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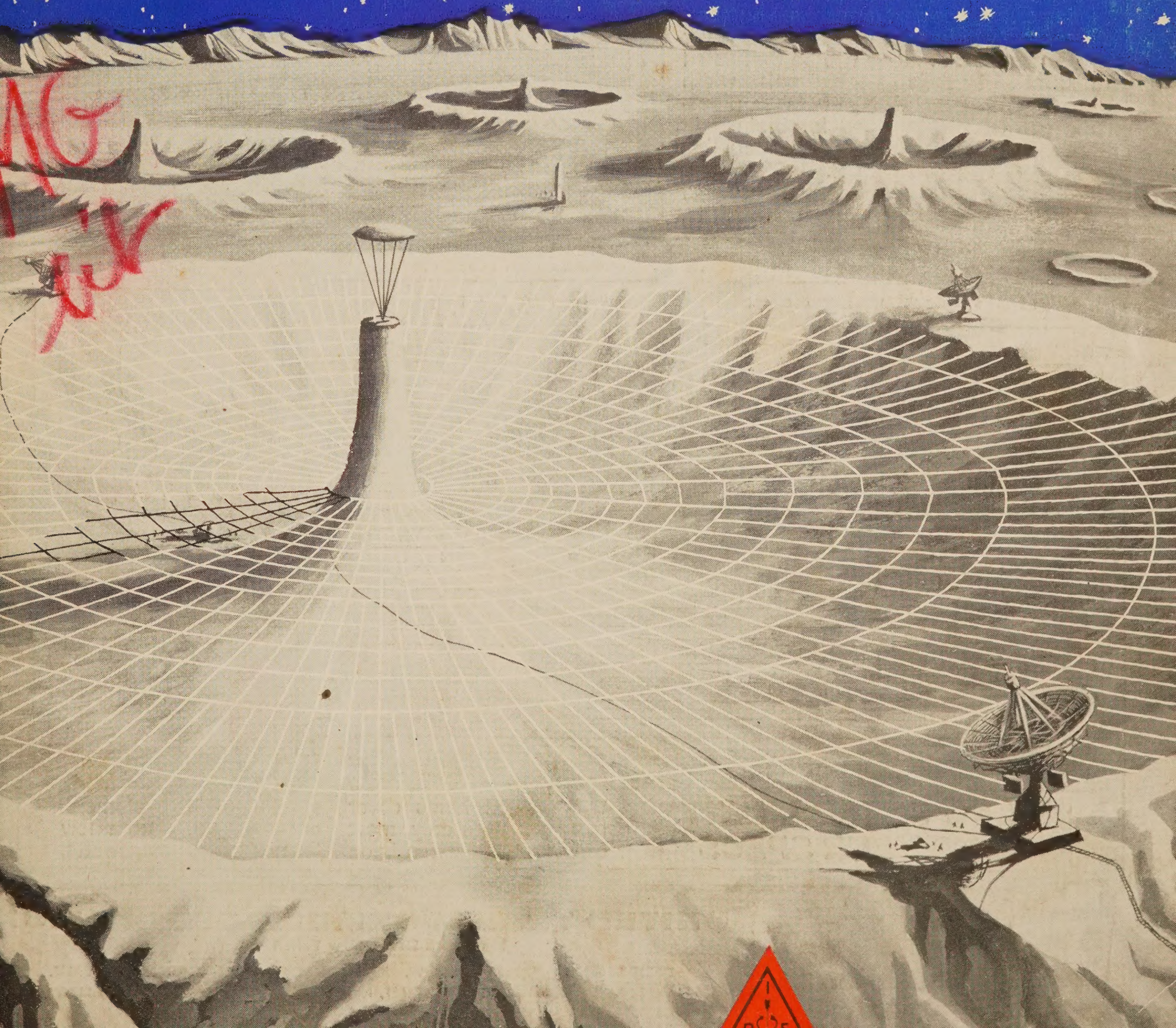
Proceedings of the IRE

SPACE ELECTRONICS ISSUE



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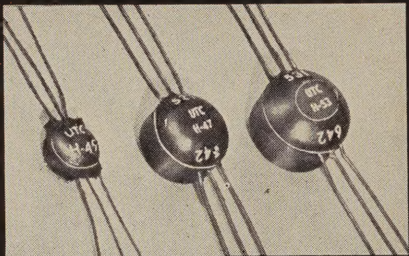
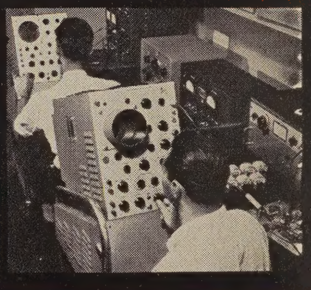




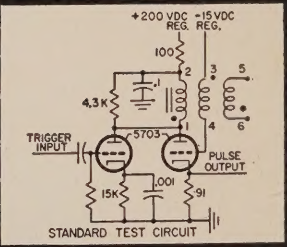
DEFINITIONS

Amplitude: Intersection of leading pulse edge with smooth curve approximating top of pulse.
Pulse width: Microseconds between 50% amplitude points on leading and trailing pulse edges.
Rise Time: Microseconds required to increase from 10% to 90% amplitude.
Overshoot: Percentage by which first excursion of pulse exceeds 100% amplitude.
Droop: Percentage reduction from 100% amplitude a specified time after 100% amplitude point.
Backswing: Negative swing after trailing edge as percentage of 100% amplitude.

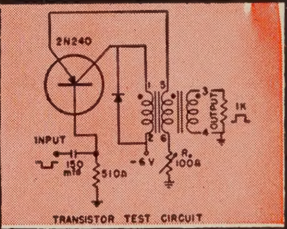
APPROX. DCR, OHMS				BLOCKING OSCILLATOR PULSE					COUPLING CIRCUIT CHARACTERISTICS						
Type No.	1-2	3-4	5-6	Width μ Sec.	Rise Time	% Over Shoot	Droop %	% Back Swing	P Width μ Sec.	Volts Out	Rise Time	% Over Shoot	Droop %	% Back Swing	Imp. in, out, ohms
H-45	3	3.5	4	.05	.022	0	20	10	.05	17	.01	20	0	35	250
H-46	5.5	6.5	7	.10	.024	0	25	10	.10	19	.01	30	10	50	250
H-47	3.7	4.0	4	.20	.026	0	25	8	.20	18	.01	30	15	65	500
H-48	5.5	5.8	6	.50	.03	0	20	5	.50	20	.01	30	20	65	500
H-49	8	8.5	9	1	.04	0	20	10	1	24	.02	15	15	65	500
H-50	20	21	22	2	.05	0	20	10	2	27	.05	10	15	35	500
H-51	28	31	33	3	.10	1	20	8	3	26	.07	10	10	35	500
H-52	36	41	44	5	.13	1	25	8	5	23	.15	10	10	45	1000
H-53	37	44	49	7	.28	0	25	8	7	24	.20	10	10	50	1000
H-54	50	58	67	10	.30	0	20	8	10	24	.25	10	10	50	1000
H-55	78	96	112	16	.75	0	20	10	16	23	.40	5	15	20	1000
H-56	93	116	138	20	1.25	0	25	10	20	23	.6	5	10	10	1000
H-57	104	135	165	25	2.0	0	30	10	25	24	1.5	5	10	10	1000
H-60	.124	.14	.05	.05	.016	0	0	30	.05	9.3	.012	0	0	20	50
H-61	.41	.48	.19	.1	.016	0	0	30	.1	8.2	.021	0	0	15	50
H-62	.78	.94	.33	.2	.022	0	0	18	.2	7.4	.034	0	5	12	100
H-63	1.86	2.26	.70	.5	.027	2	10	20	.5	7.5	.045	0	20	25	100
H-64	3.73	4.4	1.33	1	.033	0	12	25	1	7	.078	0	15	23	100
H-65	6.2	7.3	2.22	2	.066	0	15	25	2	6.6	.14	0	10	20	100
H-66	10.2	12	3.6	3	.087	0	18	30	3	6.8	.17	0	10	20	100
H-67	14.5	17.5	5.14	5	.097	0	23	28	5	7.9	.2	0	18	28	200
H-68	42.3	52.1	14.8	10	.14	0	15	28	10	6.5	.4	0	15	30	200

Note: 0 = Negligible

Vacuum Tube Type Ratio 1:1:1



Transistor Type Ratio 4:4:1



H-45, 46, 60 thru 68 are 3/8 cube, 1 gram **H-47 thru 52, 9/16 cube 4 grams** **H-53 thru 57, 5/8 cube 6 grams**

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April, 1960 VOLUME 48, NUMBER 4

published monthly by The Institute of Radio Engineers, Inc.

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COVER

The craters of the moon resemble the splash of a gigantic drop of water, with a high rim around the edge and a tall cone protruding from the center. This conformation has led the organizer of this special issue, Conrad Hoeppner of Radiation, Inc., to suggest that when man reaches the moon he utilize a moon crater as the framework for a giant parabolic antenna, one to two miles in diameter, to handle all communication with the earth. To produce a parabola rather than a catenary, the wires suspended from the crater rim must be uniformly weighted in the horizontal plane. This is achieved by properly selecting the size and spacing of the cross wires. Since the earth's position will appear to oscillate several degrees during each orbital cycle of the moon, provision would be made to shift the antenna beam by mounting the antenna feed structure, located atop the center cone of the crater, on tracks so that it could be moved from side to side of the antenna focal point.

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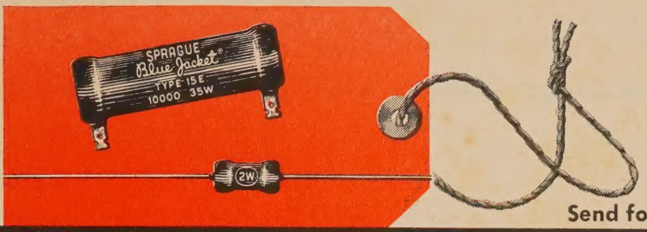
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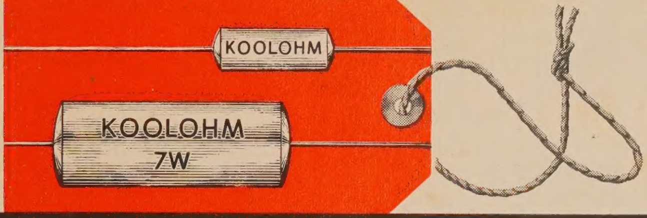
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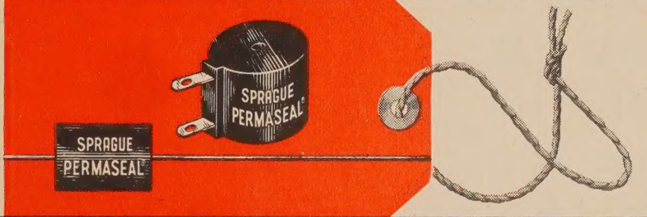
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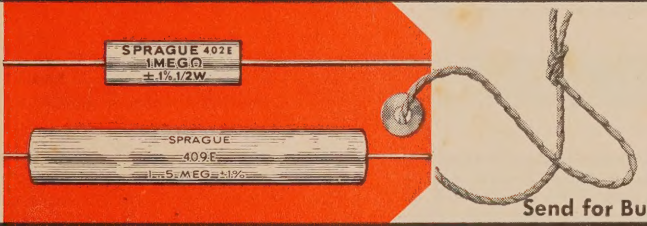
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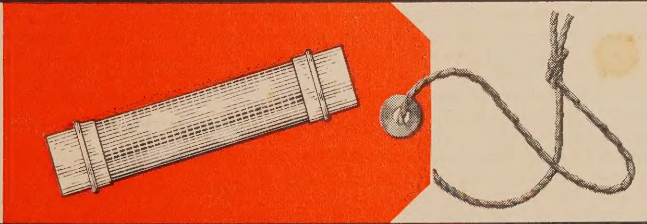

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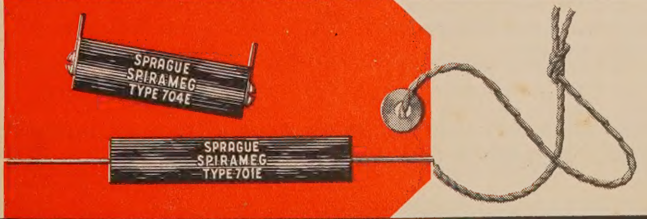
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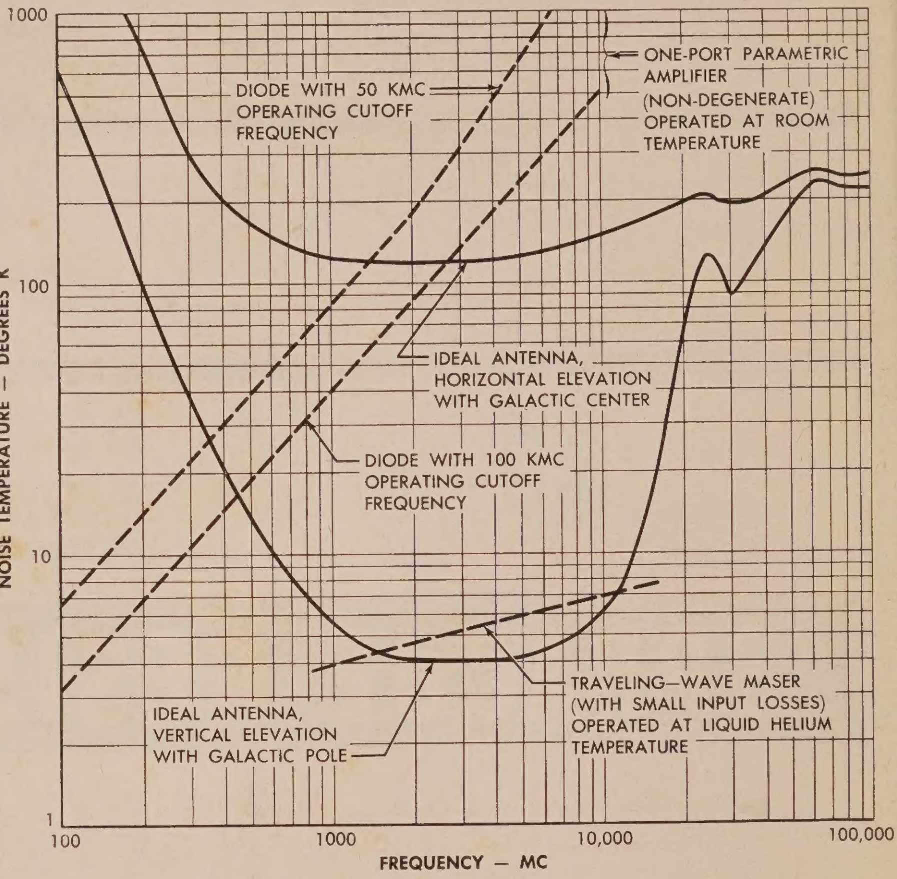
In two articles that appeared on this page Jack Greene of our Department of Applied Electronics, discussed noise factor vs. noise temperature and antenna noise temperature. He now demonstrates the extreme importance of environment in overall receiving system sensitivity. Environment has been ignored too often when in reality, with modern low noise systems, it is often the limiting factor.

Sensitivity Limitations Set by Ideal Antennas, Masers and Parametric Amplifiers



The low noise performance of the solid-state maser and the parametric amplifier has been well established. In turn, this exceptional performance has caused a reappraisal of receiving antenna design since, in many instances, the antenna noise may determine the overall system sensitivity. Thus, it is of interest to examine the limits on antenna noise temperature present even with ideal antennas, and to further examine the limits on receiver noise temperature set by masers and parametric amplifiers.

The concepts of antenna noise temperature and effective receiver noise temperature were discussed previously.[1, 2] To summarize, the sum of the antenna noise temperature and the effective receiver noise temperature determines the effective system noise temperature, and therefore the sensitivity of the complete system to received signals. Antenna noise temperature is a measure of the noise power available from the antenna terminals per unit bandwidth; it is caused by galactic noise and the absorption in the antenna environment (with its concomitant radiation) acting on the antenna gain pattern. Effective receiver noise temperature, T_e, is a term now widely used as a measure of receiver sensitivity; it is related to receiver noise factor, F, by the expression $T_e = (F - 1)290$, and represents the internally generated excess noise temperature of the receiver.

The noise temperature of an ideal antenna is readily determined if the antenna pointing angle, operating frequency, and weather conditions are specified. (A nonideal antenna with losses, spillover, and minor lobes will have reduced gain and a generally higher noise temperature; an exact knowledge of the nonideal gain pattern is required to accurately determine the noise temperature in this case.)[3] The limiting values for the noise temperature of an ideal antenna, assumed located on the earth's surface, occur as follows: (1) the minimum occurs when the antenna is pointed vertically upward (minimum atmospheric attenuation) at the galactic pole (minimum galactic noise); (2) the maximum occurs when the antenna is pointed along the horizon (maximum atmospheric attenuation) at the galactic center (maximum galactic noise). These limits are plotted in the accompanying figure as a function of frequency, under the assumption of moderate relative humidity in the atmosphere. It should be recognized that even for a fixed antenna pointing angle, the antenna noise temperature will vary with time because of the varying galactic noise component introduced by the earth's rotation, and also because of varying weather conditions.

An ideal receiver has an effective noise temperature of 0°K. Present solid-state masers approach ideal performance primarily because they are operated in liquid helium baths. (As improved maser materials become available, the stringent refrigeration requirement can possibly be relaxed without a degradation in noise performance.) The effective noise temperature obtainable from a traveling-wave maser with small input cable loss is also indicated on the accompanying figure, and in general is somewhat larger than the minimum antenna noise temperature.

The junction-diode parametric amplifier has received considerable attention because it promises low effective noise temperatures without the need for refrigeration. In fact, for a lossless diode, the noise performance of an unrefrigerated parametric amplifier would closely match that of present masers. Unfortunately, available junction diodes do have moderate losses, and therefore, their room temperature performance departs significantly from ideal performance. The noise performance expected from one-port (nondegenerate) parametric amplifiers operated at room temperature with linearly graded silicon varactors is also shown on the accompanying figure.[4] As indicated, the use of unrefrigerated parametric amplifiers would presently be restricted to the lower microwave frequencies in optimum systems. (The noise performance of the parametric amplifier using lossy diodes can be improved considerably by refrigeration;[5] however, this requires diodes specifically designed for low temperature operation, and such diodes are not yet commercially available.)

In conclusion, limits have been established for the noise temperature contributions of ideal antennas and available low noise receivers. The traveling-wave maser is a nearly optimum counterpart for an antenna with ideal characteristics, and as diode manufacturing techniques improve, unrefrigerated parametric amplifiers will seriously challenge the maser in many system applications. Finally, although the most sensitive receiving system possible is now nearly a reality with earth-bound antennas, further improvements in receiver noise temperature may become necessary for antennas located in space, where the antenna noise temperature generally decreases significantly.

1. "Noise Factor and Noise Temperature," Proc. IRE, vol. 46, p. 2A, January 1958.
2. "Antenna Noise Temperature," Proc. IRE, vol. 46, p. 4A, May 1958.
3. R. Gardner, "Final Engineering Report on Antenna Noise Temperature Study," AIL Report No. 3304-11, November 1957. (Performed under Contract DA-49-170-sc-1547.)
4. J. C. Greene and E. W. Sard, "Optimum Noise and Gain-Bandwidth Performance for a Practical One-Port Parametric Amplifier," submitted for publication in Proc. IRE.
5. M. Uenohara and W. M. Sharpless, "An Extremely Low-Noise 6-Kmc Parametric Amplifier Using Gallium-Arsenide Point-Contact Diodes," Proc. IRE, vol. 47, p. 2114-2115, December 1959.

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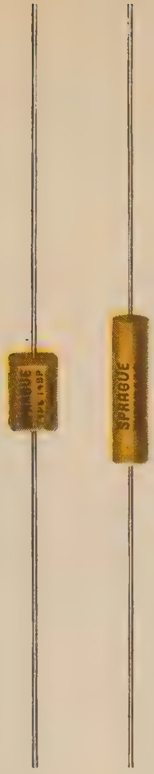
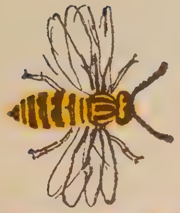


smallest

of Sprague's film capacitors for entertainment and commercial electronics



YELLOW-JACKET® WRAPPER-PROTECTED FILMITE 'E' CAPACITORS

are the smallest of Sprague's family of film capacitors. Type 148P and 149P Yellow-Jackets are designed for compact radio receivers, test equipment, communications equipment, and similar applications. They are especially suited for transistorized and low-voltage tube circuits, as well as all other applicable circuits in which size, weight, and cost are important considerations.

Yellow-Jacket capacitor sections are of extended foil design...wound from ultra-thin, especially selected polyester film and thin gage foil under carefully controlled atmospheric conditions. They are protected against moisture by an outer wrap of polyester film. End seals are of a plastic resin which bonds securely with the film wrap in order to assure long service life.

This construction results in a light-weight capacitor of minimum size, having a distinct space advantage over metal-encased, molded, or wax-coated cardboard-case tubulars of comparable ratings.

Yellow-Jacket Type 148P (cylindrical) and 149P (semi-oval) capacitors are recommended for use in applications requiring reliable operation within the temperature range of −55 C to +85 C at rated working voltages of 100, 200, 400, and 600 volts d-c.

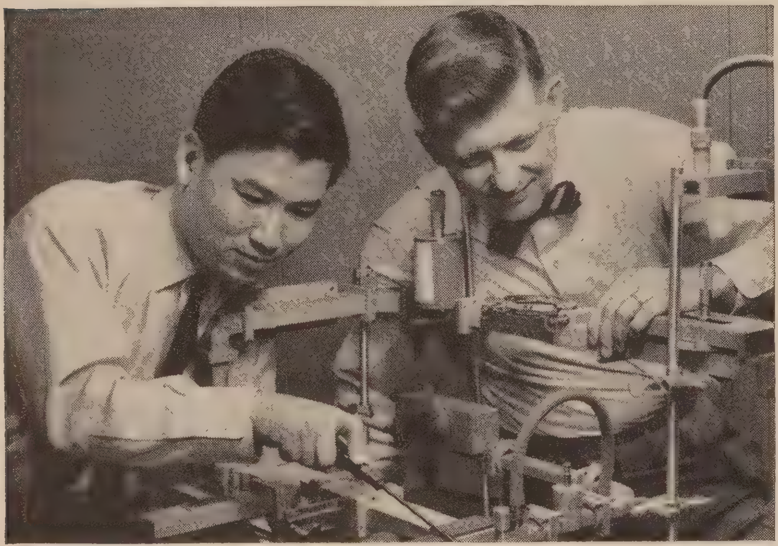
For complete technical data on these Yellow-Jackets, write for Bulletin 2063A to Technical Literature Section, Sprague Electric Company, 235 Marshall St., North Adams, Mass.

SPRAGUE®
THE MARK OF RELIABILITY

SPRAGUE COMPONENTS:

CAPACITORS • RESISTORS • MAGNETIC COMPONENTS • TRANSISTORS • INTERFERENCE FILTERS • PULSE NETWORKS
HIGH TEMPERATURE MAGNET WIRE • CERAMIC-BASE PRINTED NETWORKS • PACKAGED COMPONENT ASSEMBLIES

THE IDEA THAT GREW FOR 100 YEARS



At Bell Laboratories, M. Uenohara (left) adjusts his reactance amplifier, assisted by A. E. Bakanowski, who helped develop first suitable diode. Extremely low "noise" is achieved when certain diodes are cooled in liquid nitrogen.

First practical diode for amplifier, shown here held by tweezers, was jointly developed by A. E. Bakanowski and A. Uhlir.

How basic scientific ideas develop in the light of expanding knowledge is strikingly illustrated by the development of Bell Laboratories' new "parametric" or "reactance" amplifier.

Over 100 years ago, scientists experimenting with vibrating strings observed that vibrations could be amplified by giving them a push at strategic moments, using properly synchronized tuning forks. This is done in much the same way a child on a swing "pumps" in new energy by shifting his center of gravity in step with his motion.

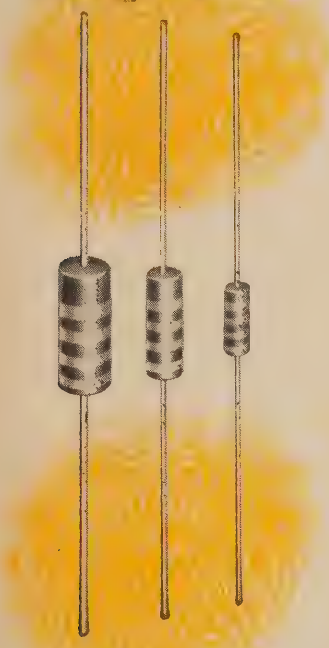
At the turn of the century, scientists theorized that *electrical* vibrations, too, could be amplified by synchronously varying the *reactance* of an inductor or capacitor. Later amplifiers were made to work on this principle but none at microwave frequencies.

Then came the middle 50's. Bell Telephone Laboratories scientists, by applying their new transistor technology, developed semiconductor diodes of greatly improved capabilities. They determined theoretically *how* the electrical capacitance of these new diodes could be utilized to amplify at *microwave* frequencies. They created a new microwave amplifier with far less "noise" than conventional amplifiers.

The new reactance amplifier has a busy future in the battle with "noise." At present, it is being developed for applications in tropospheric transmission and radar. But it has many other possible applications, as well. It can be used, for instance, in the reception of signals reflected from satellites. It is still another example of the continuing efforts to improve your Bell System communications.

BELL TELEPHONE LABORATORIES

WORLD CENTER OF COMMUNICATIONS RESEARCH AND DEVELOPMENT



how many Resistors have you soldered recently?

It's no trick today to obtain resistors that give everything you need in the way of conventional characteristics such as load life, resistance-temperature, temperature cycling, and so on.

But what a whale of a difference when it comes to "solderability"! Try the different makes for yourself and see. Whether you solder by hand or by automatic dipping, you'll find that Stackpole Coldite 70+ resistors solder lots better, lots faster and lots more surely.

Just hit 'em with solder and they stay soldered—because they're the only resistors whose leads get an extra final solder dip *in addition* to the usual tin-lead coating. You get faster production, fewer rejected assemblies. And there's less chance of trouble developing after your products reach the field.

COMPARE THESE "SPECS"! — Write for Stackpole Resistor Bulletin giving complete scorecard for Coldite 70+ (cold-molded) resistors in relation to MIL as well as commercial specifications. And remember that they give you unmatched solderability in the bargain—at no extra cost!

Electronic Components Division **STACKPOLE CARBON CO.,** *St. Marys, Pa.*

Ceramag® ferromagnetic cores • Slide and Snap switches • Variable composition resistors **Ceramagnet®** ceramic magnets • Fixed composition capacitors • Electrical contacts Brushes for all rotating electrical equipment Hundred of related carbon, graphite, and metal powder products.

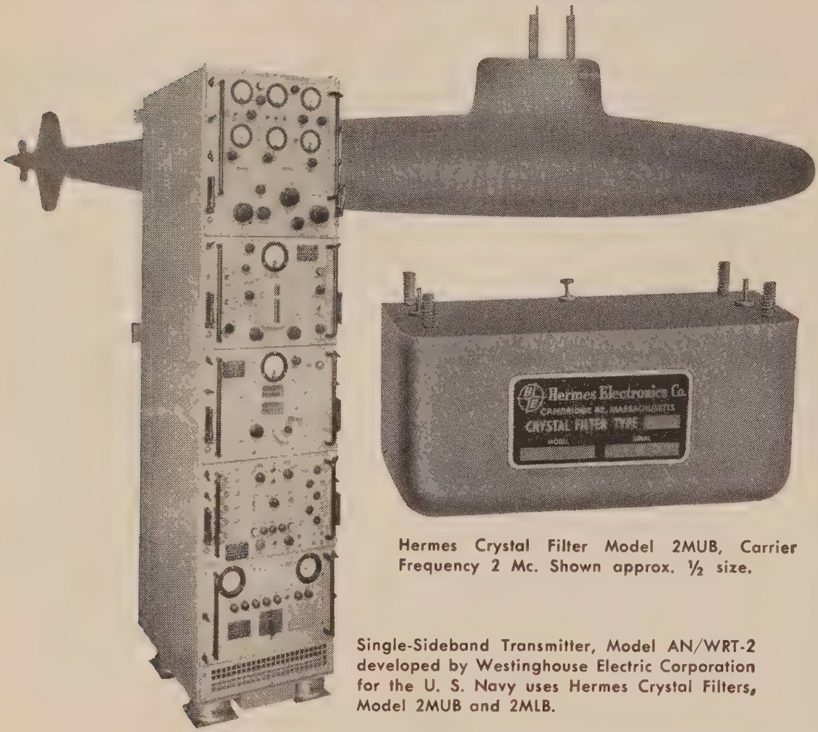
STACKPOLE

Coldite 70+®

fixed composition resistors

FIRST Navy Militarized SSB Transmitter Generates Cleaner Signal Using

HERMES CRYSTAL FILTERS



Hermes Crystal Filter Model 2MUB, Carrier Frequency 2 Mc. Shown approx. ½ size.

Single-Sideband Transmitter, Model AN/WRT-2 developed by Westinghouse Electric Corporation for the U. S. Navy uses Hermes Crystal Filters, Model 2MUB and 2MLB.

Recently installed on the atomic submarine SKIPJACK (SSN585), the Westinghouse Electric AN/WRT-2 SSB Transmitter is now standard Navy equipment.

Single sideband signals are generated in the AN/WRT-2 by the selective filter method employing Hermes 2MUB and 2MLB Crystal Filters. These 2.0 Mc Crystal Filters not only offer all the basic advantages of the filter SSB generation method, but reduce the number of heterodyning stages required to translate the modulated signal to the required output frequency. The attendant decrease in unwanted signal generation results in a cleaner signal. The AN/WRT-2 is also a more reliable transmitter because fewer components are used.

In addition to the 2.0 Mc Crystal Filters, Hermes has also supplied SSB units at 87 Kc, 100 Kc, 137 Kc, 1.4 Mc, 1.75 Mc, 3.2 Mc, 6 Mc, 8 Mc, 10 Mc and 16 Mc. These Crystal Filters are presently installed in airborne HF, mobile VHF and point to point UHF SSB systems.

Whether your selectivity problems are in transmission or reception, AM or FM, mobile or fixed equipment, you can call on Hermes engineering specialists to assist in the design of circuitry and the selection of filter characteristics best suited to your needs. Write for Crystal Filter Short Form Catalog.

A limited number of opportunities are available to experienced circuit designers. Send résumé to Dr. D. I. Kosowsky.

Hermes
ELECTRONICS CO.
75 CAMBRIDGE PARKWAY, CAMBRIDGE 42, MASSACHUSETTS

Meetings with Exhibits

● As a service both to Members and the industry, we will endeavor to record in this column each month those meetings of IRE, its sections and professional groups which include exhibits.

△

April 20-22, 1960

SWIRECO, Southwestern IRE Regional Conference & Electronics Show, Shamrock-Hilton Hotel, Houston, Texas.

Exhibits: Mr. A. D. Seixas, SWIRECO, P.O. Box 22331, Houston, Texas.

May 2-4 1960

National Aeronautical Electronics Conference, Dayton Biltmore Hotel, Dayton, Ohio.

Exhibits: Mr. Edward M. Lisowski, General Precision Lab., Inc., Suite 452, 333 West First St., Dayton 2, Ohio.

May 2-6, 1960

Western Joint Computer Conference, Fairmont Hotel, San Francisco, Calif.

Exhibits: Mr. H. K. Farrar, Pacific Tel. & Tel. Co., 140 New Montgomery St., San Francisco 5, Calif.

May 23-25, 1960

1960 National Telemetering Conference, Miramar Hotel, Santa Monica, Calif.

Exhibits: Mr. William Van Dyke, Douglas Aircraft Co., Inc., El Segundo, Calif.

May 24-26, 1960

Seventh Regional Technical Conference & Trade Show, Olympic Hotel, Seattle, Wash.

Exhibits: Mr. Rush Drake, 1806 Bush Place, Seattle 44, Wash.

May 24-26, 1960

Armed Forces Communications & Electronics Association Convention and Exhibit, Sheraton-Park Hotel, Washington, D.C.

Exhibits: Mr. William C. Copp, 72 West 45th St., New York 36, N.Y.

June 20-21, 1960

Chicago Spring Conference on Broadcast and Television Receivers, Graemere Hotel, Chicago, Ill.

Exhibits: Mr. Stanley Hopper, Zenith Radio Corp., 6001 W. Dickens Ave., Chicago 39, Ill.

June 27-29, 1960

National Convention on Military Electronics, Sheraton-Park Hotel, Washington, D.C.

Exhibits: Mr. L. David Whitelock, BuShips, Electronics Div., Dept. of Navy, Washington, D.C.

August 1-3, 1960

Fourth Global Communications Symposium, Hotel Statler, Washington, D.C.

Exhibits: Mr. Robert O. Brady, Office of the Chief Signal Officer, U. S. Army Signal Corps, Washington, D.C.

(Continued on page 10A)

For High Accuracy—Broad Band Noise Figure Measurement

Therma-Node
KAY ELECTRIC CO.
PINE BROOK, N.J.

KAY
Therma-Node

Basic Noise Source
CAT. NO. 770

Available Noise
Accurate to ±0.1

3 Noise Heads
Cover 1 kc to 1000 mc

Portable
Can Be Operated from
117 V, 60 cycles or 24 V dc

SPECIFICATIONS

STANDARD NOISE HEAD: (Head A furnished with **Therma-Node**) covers 2 to 1000 mc; output impedance 50 ohms, unbalanced N type connectors.

Max. VSWR, variable tuned, 1.1 from 10 to 1000 mc.

Max. VSWR, fixed tuned, 1.1 from 10 to 100 mc; 1.2 from 6 to 300 mc; 1.4 from 4 to 400 mc; 2 from 2 to 500 mc.

INTERCHANGEABLE LOW FREQUENCY NOISE HEAD: (Head B) covers 1 kc to 350 mc; output impedance 50 ohms, unbalanced.

Max. VSWR 1.1 from 3 kc to 100 mc; 1.2 from 2 kc to 250 mc; 1.4 from 1 kc to 350 mc.

AMBIENT SOURCE PROBE for use with A and B Noise Heads:

Frequency range—0 to 1000 mc.
Output impedance—50 ohms, unbalanced.
Max. VSWR = 1.1
Accuracy of indicated temperature—2 EM—±1%

SELECTABLE-IMPEDANCE NOISE HEAD: (Head C) covers 0.25 to 400 mc, balanced or unbalanced output. Selectable output impedances of 50, 100 and 200 ohms are provided.

Max. VSWR—1.1 from 1 to 75 mc; 1.2 from 0.5 to 100 mc; 1.4 from 0.25 to 400 mc.

Max. VSWR difference between ambient and hot sources is 0.05 (hot and ambient sources contained in same probe).

Weight: 8 pounds in carrying case.

Dimensions: 11.5 x 8 x 4.75 inches.

Operates on 117 V, 60 cps, or 24 V dc.

Price: $495.00, f.o.b. factory.
Low Frenquency Noise Head (B): $175.00
Selected Impedance Head (C): $125.00

Through refinement of a basic noise generation technique—thermal noise from a heated resistive element—the new Kay *Therma-Node* achieves high accuracy over an extreme wide range of frequencies. *Therma-Node's* resistive element, contained in the noise head, is heated to a normal 2200°K, generating adequate noise-power for accurate noise figure measurements to 10 db. Nominal fixed available noise temperature ranging between 2000 and 2400°K may be read directly on the panel meter to 2% accuracy. A single tuning element, contained in the noise head, provides a fixed range of 2 to 500 mc, and may be tuned to extend the range to 1000 mc. An optional, interchangeable head extends measurement down to 1 kc. Ambient termination is supplied. Both heads have output impedances of 50 ohms, unbalanced. Both heads can be used without connecting coaxial cables, thus eliminating cable errors.

A selectable-impedance noise head, covering the range .25 to 400 mc, and furnishing output impedances of 50, 100 and 200 ohms, balanced and unbalanced, is available as an accessory.

The inexpensive resistive element in the *Therma-Node* noise head has a life expectancy of 10,000 hours in either intermittent or continuous service. Because the few active components in the *Therma-Node* are solid state devices, its inherent stability results in long term accuracy and freedom from maintenance.

OTHER KAY NOISE GENERATORS

Instrument & Cat. No.	Frequency Range (mc)	Noise Figure Range (db)	Output Impedance (ohms)	Price f.o.b. factory
Mega-Node® 240-B	5-220	0-16 at 50 ohms 0-23.8 at 300 ohms	unbal.—50, 75, 150, 300, ∞ bal.—100, 150, 300, 600, ∞	$365.00
Mega-Node 175-A	50-500	0-19	balanced—300	$365.00
Mega-Node 403-A	3-500	0-19	unbalanced—50	$365.00
Mega-Node 3000	1-3000	0-20	unbalanced—50	$790.00
Rada-Node® 600-A	5-400	0-23.8 depending on impedance	unbalanced as specified	$1495.00
	10-3000	0-20	unbal. nom. 50	$1965.00
	1120-26,500	15.28 or 15.8	waveguide	†
*Microwave Mega-Nodes**	1120-26,500	15.28 or 15.8	waveguide	$175.00 to $595.00

† Price varies with **Microwave Mega-Node** used as accessory.
* Ideally suited for noise figure measurement in radar communication.

WRITE FOR NEW
KAY CATALOG

KAY ELECTRIC COMPANY
Dept. I-4 Maple Avenue, Pine Brook, N.J. CApital 6-4000

TOWER FOOTING INSULATORS FOR SELF-SUPPORTING RADIATORS
MAST BASE INSULATORS
RADIO GUY INSULATOR

LAPP ANTENNA TOWER INSULATORS

We at Lapp are mighty proud of our record in the field of tower insulators. Over 30 years ago, the first insulated broadcasting tower was erected—on Lapp insulators. Since then, most of the large radio towers in the world have been insulated and supported by Lapp insulators. Single base insulator units for structures of this type have been design-tested to over 3,500,000 pounds.

A thorough knowledge of the properties of porcelain, of insulator mechanics and electrical qualities has been responsible for Lapp's success in becoming such an important source of radio insulators. Write for description and specification data on units for any antenna structure insulating requirement. Lapp Insulator Co., Inc., Radio Specialties Division, 223 Sumner Street, LeRoy, N. Y.

Lapp

Meetings with Exhibits

(Continued from page 8A)

August 23-26, 1960
WESCON, Western Electronic Show and Convention, Ambassador Hotel & Memorial Sports Arena, Los Angeles, Calif.
Exhibits: Mr. Don Larson, WESCON, 1435 LaCienega Blvd., Los Angeles, Calif.

September 19-21, 1960
National Symposium on Space Electronics & Telemetry, Shoreham Hotel, Washington, D.C.
Exhibits: Mr. Leon King, Jansky and Bailey, 1339 Wisconsin Ave., N.W., Washington, D.C.

October 3-5, 1960
Sixth National Communications Symposium, Hotel Utica & Utica Municipal Auditorium, Utica, N.Y.
Exhibits: Mr. R. E. Bischoff, 19 Westminster Road, Utica, N.Y.

October 10-12, 1960
National Electronics Conference, Hotel Sherman, Chicago, Ill.
Exhibits: National Electronics Conference, Inc., 228 North La Salle St., Chicago 1, Ill.

October 24-26, 1960
East Coast Aeronautical & Navigational Electronics Conference, Lord Baltimore Hotel & 7th Regiment Armory, Baltimore, Md.
Exhibits: Mr. R. L. Pigeon, Westinghouse Electric Corp., Air Arm Div., P.O. Box 746, Baltimore, Md.

Oct. 31-Nov. 2, 1960
13th Annual Conference on Electrical Techniques in Medicine & Biology, Sheraton-Park Hotel, Washington, D.C.
Exhibits: Mr. Lewis Winner, 152 West 42nd St., New York 36, N.Y.

November 14-16, 1960
Mid-America Electronics Convention (MAECON), Municipal Auditorium, Kansas City, Mo.
Exhibits: Mr. John V. Parks, Bendix Aviation Corp., P.O. Box 1159, Kansas City 41, Mo

November 15-17, 1960
Northeast Electronics Research & Engineering Meeting (NEREM), Boston Commonwealth Armory, Boston, Mass.
Exhibits: Miss Shirley Whitcher, IRE Boston Office, 73 Tremont St., Boston, Mass.

∆

Note on Professional Group Meetings: Some of the Professional Groups conduct meetings at which there are exhibits. Working committeemen on these groups are asked to send advance data to this column for publicity information. You may address these notices to the Advertising Department and of course listings are free to IRE Professional Groups.

THE G. C. DEWEY CORPORATION
For scientific research and development
with intellectual integrity

SCIENTIFICALLY ORIENTED to *achieve significant results for government and civilian agencies–in the broad areas of defense physics ... weapons system concepts and evaluation ... electronic technology–this organization applies creative scientific thinking ... to advanced problems of nuclear and plasma physics ... to unique computer programming techniques ... to original electronic design criteria ... to systems analyses that meet measure of effectiveness standards.*

THE G. C. DEWEY CORPORATION, 202 East 44th Street, N. Y. C. 17

Physicists, mathematicians and engineers with advanced degrees,
write for information on professional career opportunities.

For original equipment, direct replacement

NEC tubes with new doped-nickel cathode

6R-P10

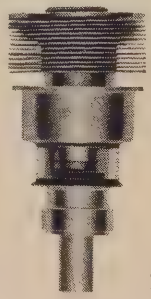
6R-R8

Both tube series described here use NEC's new doped-nickel cathode core material. This 10-year development increases emission without raising operating temperature. Oxide evaporation rate is lower than any known core material. Operating data show tube life is extended up to 50%.

WIDE-BAND AMPLIFIER TUBES: Development began seven years ago with the 6R-R8, which was used in Japan's first microwave link. A modification, 6R-R8C, with very low distortion factor, is used in coaxial amplifiers. 6R-P10 Power Amplifier Pentode, with high mutual conductance and small capacitance, is designed for larger power output.

Type	Name	Cathode Rating		Screen and Plate Supply Voltage Eb (V) Ec2 (V)	Plate Current Ib (mA)	Trans-conductance Gm (μ℧)	Capacitances		Interchangeable Tubes
		Volts Ef (V)	Amp If (A)				Input μμF	Output μμF	
6R-R8	Sharp-Cutoff Pentode	6.3	0.3	150	13	12,500	7.8	3.2	with WE404A
6R-R8C	Sharp-Cutoff Pentode	6.3	0.3	150	13	12,500	7.3	3.2	with WE404A
6R-P10	Power Amplifier Pentode	6.3	0.5	150	36	13,500	10.5	2.7	——

2C40



2C39B

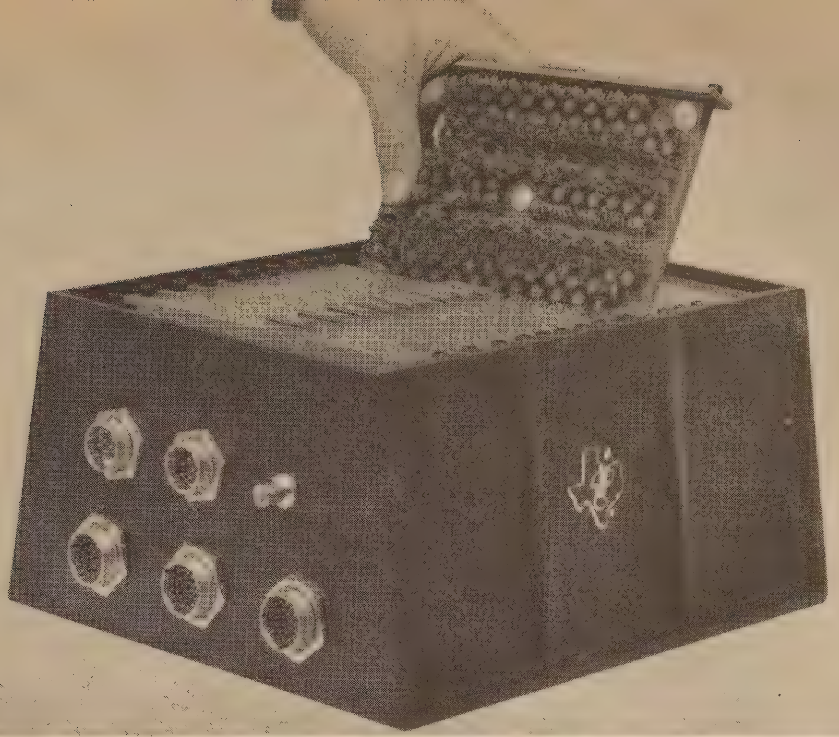
Type	Use	Cathode Rating		Maximum Plate Voltage Ev (V)	Maximum Plate Dissipation Pp (W)	Power Po (W)	Maximum Frequency f (MC)
		Voltage Ef (V)	Current If (A)				
2B22	Detector	6.3	0.75	150	—	—	1200
2C39A	Amplifier Oscillator (Continuous)	6.3	1.0	1000	100	15	2500
2C40	Amplifier Oscillator (Continuous)	6.3	0.75	500	4	0.75	3370
2C43	Amplifier Oscillator (Continuous & Pulse)	6.3	0.9	3500*	12	1.0	3370
5861	Amplifier Oscillator (Continuous)	6.3	0.4	350	10	0.5	3700

* Pulse plate Voltage (eb)

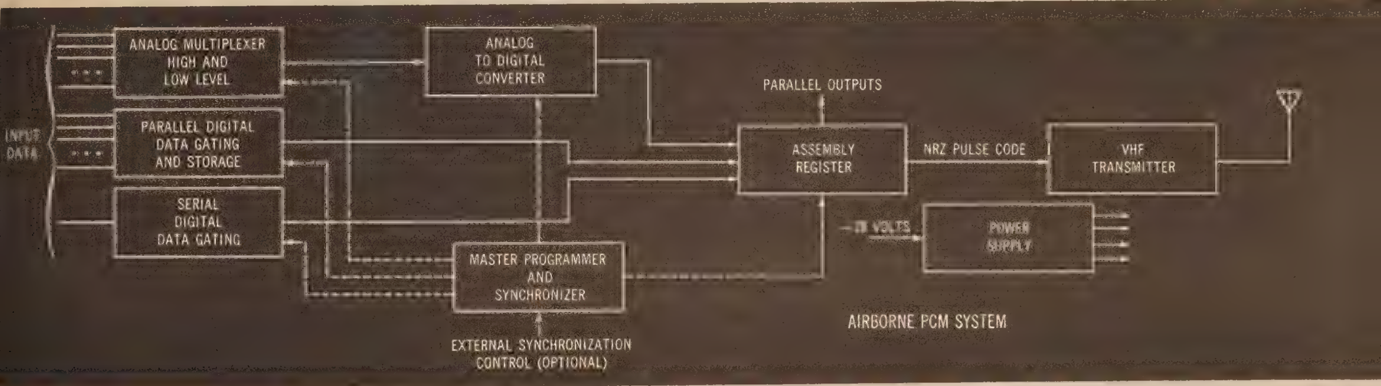
DISC-SEALED TRIODES: NEC designed the first disc-sealed tube in 1939, giving NEC many years of experience in the design and manufacture of this type of microwave tube. Each is a direct replacement under all circumstances for the corresponding type. The NEC tube will give longer life, an especially important advantage in repeater stations.

Please write for specification sheets.

NEC *Nippon Electric Company Ltd.* Tokyo, Japan
COMPONENTS / SYSTEMS



NEW FROM TEXAS INSTRUMENTS!


ANALOG MULTIPLEXER HIGH AND LOW LEVEL
INPUT DATA
PARALLEL DIGITAL DATA GATING AND STORAGE
SERIAL DIGITAL DATA GATING
ANALOG TO DIGITAL CONVERTER
MASTER PROGRAMMER AND SYNCHRONIZER
EXTERNAL SYNCHRONIZATION CONTROL (OPTIONAL)
PARALLEL OUTPUTS
ASSEMBLY REGISTER
NRZ PULSE CODE
VHF TRANSMITTER
28 VOLTS
POWER SUPPLY
AIRBORNE PCM SYSTEM

High capacity, ½ cu ft, PCM telemetry system ...with system drift nulled out!

Now you can get the benefits of digital techniques — accuracy, speed and reliability — in compact pulse code modulation telemetry systems from Texas Instruments. The 25-pound, ½ cubic foot package shown uses only solid state devices, and may be used to drive any of the compact TI transmitters dictated by the application. The system multiplexes and encodes 64 analog channels; and processes five 8-bit parallel digital data channels plus a serial digital data channel at a nominal bit rate of 200 kc.

A key feature of the system is its high-speed analog multiplexer which handles low- and high-level data, or a combination of both, with *only a single low-level amplifier*. Overall accuracy of the system is ±0.25% — made possible by a unique bi-directional servo loop that nulls out system drift. The system is packaged in individual modules so that it can be rapidly modified to fit the needs of other missiles or space vehicles.

PCM is only one of several advanced telemetry projects at Texas Instruments. Others include the development and/or production of analog systems and equipments for Bomarc, Corvus, Pershing, Minuteman, Titan, Centaur, and Project Mercury.

For detailed information about PCM telemetry or other TI missile electronic system capabilities, please contact SERVICE ENGINEERING:

TEXAS INSTRUMENTS
INCORPORATED
6000 LEMMON AVENUE
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APPARATUS DIVISION

IRE News and Radio Notes

CURRENT IRE STATISTICS

(As of February 29, 1960)

Membership—79,646
Sections*—105
Subsections*—27
Professional Groups*—28
Professional Group Chapters—261
Student Branches†—184

* See March, 1960 issue for a list.
† See October, 1959 issue for a list.

Calendar of Coming Events and Authors' Deadlines*

1960

- **6th Nuclear Congress, N. Y. Coliseum. New York, N. Y., Apr. 4–8.**
- **14th Spring Tech. Conf., Cincinnati, Ohio, Apr. 12–13.**
- **Conf. on Automatic Tech., Sheraton-Cleveland Hotel, Cleveland, Ohio, Apr. 18–19.**
- **Int'l Symp. on Active Networks and Feedback Systems, Engrg. Soc. Bldg. Auditorium, New York, N. Y., Apr. 19–21.**
- **Int'l Symp. on Active Networks and Feedback Systems, Polytechnic Inst. of Brooklyn, Brooklyn, N. Y., Apr. 19–21.**
- **1960 SWIRECO (Southwestern IRE Regional Conf. and Electronics Show), simultaneously with the Nat'l. PGME Conf., Houston, Texas, Apr. 20–22.**
- **Natl. Aeronautical Electronics Conf., Dayton-Biltmore and Miami Hotels, Dayton, Ohio, May 1–3.**
- **URSI-IRE Spring Mtg., Sheraton Park Hotel and NBS, Washington, D. C., May 2–5.**
- **Western Joint Computer Conf., San Francisco, Calif., May 2–6.**
- Symp. on Graduate Programs in Bio-Medical Engrg., Univ. of Vermont, Burlington, May 5–6.
- **PGMTT Natl. Symp., San Diego, Calif., May 9–11.**
- **Electronic Components Conf., Hotel Washington, Washington, D. C., May 10–12.**
- **Natl. Telemetering Conf., Miramar Hotel, Santa Monica, Calif., May 23–25.**
- **7th Reg. Tech. Conf. & Trade Show, Olympic Hotel, Seattle, Wash., May 24–26.**
- **6th Radar Symp., Ann Arbor, Mich., June 1–3.**
- Inst. on Recent Advances in Solid State Devices, Marquette Univ., Milwaukee, Wis., June 1–2.
- 10th Ann. Conv. of Soc. of Women Engrs., Benjamin Franklin Hotel, Seattle, Wash., June 9–11.
- **Radio Frequency Interference Symp., Washington, D.C., June 13–14.**

* DL = Deadline for submitting abstracts.

(Continued on page 15A)

ANNOUNCE SYMPOSIUM ON SUPERCONDUCTIVE TECHNIQUES FOR COMPUTING SYSTEMS

A Symposium on Superconductive Techniques for Computing Systems will be held on May 17–19, 1960, sponsored by the Information Systems Branch, Office of Naval Research. The Symposium will be held in the Department of Interior Auditorium on C Street, between 18th and 19th Streets, N.W., Washington, D. C.

The purpose of this Symposium is to bring together the scientists and engineers currently engaged in cryogenic device research in order to present a complete picture of the present status of the applications of superconductivity to computers, computing systems, and information processing devices. Invited papers emphasizing device aspects have been solicited from most of the organizations in the United States which are now involved in research of this type. Approximately 16 to 18 papers will be presented at the Symposium including those by representatives of the following activities: Burroughs Corp., Duke University, General Electric Company, International Business Machines Corp., Lincoln Laboratory of M.I.T., Arthur D. Little, Inc., University of North Carolina, Radio Corporation of America, Rutgers University, Space Technology Laboratory, and Sperry-Rand Corporation. Attendance is open to all interested technical personnel.

Individuals may receive further information and a preliminary Symposium program when available by contacting: Miss Josephine Leno, Code 430A, Office of Naval Research, Washington 25, D. C.

RUSSIAN TECHNICAL JOURNAL AVAILABLE IN TRANSLATION

The Society for Industrial and Applied Mathematics announces the appearance of the first issue of Volume IV of *Theory of Probability and Its Applications*. This is a complete translation into English of the corresponding issue of the Russian journal *Teoriya Veroyatnostei i ee Primeneniya*. During 1960 the Society will publish separately translations of all four issues of Volume IV (1959), will begin the translation of Volume V, and will publish in bound form full translations of Volumes I (1956), II (1957) and III (1958). It is expected that by early 1961 translations will be appearing within four months of publication of the Russian original.

Theory of Probability and Its Applications is a quarterly journal devoted, as its title indicates, to research papers in probability and statistics, and to related applications in physics and communication. For the most part, the journal has reported the work of Russian authors; its translation offers the first access to this material in a Western language.

The Society for Industrial and Applied Mathematics has been assisted in this translation project by a grant from the National Science Foundation.

Subscriptions to *Theory of Probability and Its Applications* are being offered at \$19.00 for four current issues (one year) (\$9.50 to members of the Society, add \$3.90 for subscriptions outside of the U. S. and Canada). Inquiries may be addressed to the Society at Box 7541, Philadelphia 1, Pa.

AIR FORCE MARS EASTERN NET CHOOSES SPEAKERS FOR APRIL

The April schedule of the Air Force MARS Eastern Technical Net, operating Sundays from 2 to 4 P.M. EST, 3295–7540–15,715 kc, has been built around the three subjects for which hundreds of requests have been received over the past few months. Through the cooperation of the Philco Technological Center it is possible to present the following series:

April 3	"Television and Scanning Techniques in the Field of Medical Electronics," J. F. Fisher, Engineering Section Manager, Government and Industrial Div., Philco Corp.
April 10	"Applications of Tunnel Diodes," J. A. Ekiss, Project Engineer, Special Projects Group, Lansdale Tube Co., Philco Corp.
April 17	Recess Date.
April 24	"Transistor Circuit Considerations," H. W. Merrihew, Director, Special Course Preparation, Philco Technological Center.

URSI SPRING MEETING PROGRAM ANNOUNCED

The program of invited papers for the Spring Meeting of URSI Combined Technical Session has been selected. In keeping with the times, it emphasizes problems associated with space. The following papers will be given:

"The Transmission Media in Space Communication," *I. Katz, Applied Physics Lab., The Johns Hopkins University, Baltimore, Md.*

"The NASA Communications Satellite Program," *L. Jaffe, Communications Satellite Program, National Aeronautics and Space Administration, Washington, D. C.*

"Advanced Research Project Agency's Satellite Communication Systems," *E. E. Harriman, ARPA, Washington, D. C.*

"Information Techniques in Space Communication," *G. E. Mueller, Space Technology, Labs. Inc., Los Angeles, Calif.*

"The Role of Ranging Experiments in Space Exploration," *S. W. Golomb, Jet Propulsion Lab., California Institute of Technology, Pasadena, Calif.*

AIEE PLANS SPACE CONFERENCE AT DALLAS, TEXAS, APRIL 11–13

The first special conference on electrical engineering in space technology sponsored by the American Institute of Electrical Engineers will be held at the Baker Hotel, Dallas, Tex., April 11–13, General Chairman B. J. Wilson, of the Naval Research Laboratory, Washington, D. C., has announced.

"Electrical aspects of space technology have become increasingly significant in fields of aero and astro-dynamics, propulsion merging with and overlapping those of metallurgy, and atomic and solid-state physics," Mr. Wilson said. "Those working in these fields have become aware of this new significance of electrical science and engineering and see the need to utilize the existing capabilities here to solve space problems."

The conference, which is expected to attract leading engineers and scientists, will explore electrical engineering aspects of communications, feedback control, electrical energy conversion and instrumentation in space. It will stress space requirements and the capabilities of electrical science and engineering to fulfill these needs.

Specifically, the conference will deal with the national space picture, the space age viewpoint on communications, control, electrical energy and instrumentation; specific missions, requirements and problems of some United States missiles and space vehicles and payloads and developments in equipment and component capabilities for space applications.

Several of the most prominent figures in the space technology and in the political world have been invited to address the two and one-half day conference.

The IRE and the American Rocket Society will participate in the conference.

13th ANNUAL ETMB CONFERENCE ISSUES CALL FOR PAPERS

Plans are now being made for the 13th Annual Conference on Electrical Techniques in Medicine and Biology, which this year will be held in Washington, D. C., October 31, November 1 and 2, 1960, at the Sheraton-Park Hotel.

As in the past, the meeting will be sponsored by the Joint Executive Committee in Medicine and Biology representing the Institute of Radio Engineers, American Institute of Electrical Engineers and the Instrument Society of America.

The theme of the conference will be the application of electronic techniques to analytical instumentation.

Scheduled for discussion are the exploration and application of new electrical and physical techniques for quantification of specific materials, determining molecular structure or providing recognizable characterization of materials of biological interest. Typical subject areas here are:

1) Polarography and specific electrodes; perm-selective membrane methods.
2) Electrical generation of titrant coulometric methods.
3) Nuclear and electron magnetic resonance analysis procedures.
4) Dielectric dispersion and high-frequency titration.
5) Mass spectrometry.
6) Microwave spectroscopy.

Papers representing original contributions in these related fields are invited.

Abstracts (200–500 words in length, which can be accompanied by supplementary illustrations) with author's name, company affiliation and position title, business and home address, telephone contact, and brief biographical sketch, should be submitted in double-spaced typewritten form (in triplicate) on or before July 1 to the Program Chairman, George N. Webb, Room 547—CSB, Johns Hopkins Hospital, Baltimore 5, Md.

RQC SYMPOSIUM SOLICITS PAPERS

Abstracts of papers to be submitted for the Seventh National Symposium on Reliability and Quality Control, jointly sponsored by the IRE, the AIEE and the ASQC, must be received by May 16, 1960. The Symposium is scheduled for January 9–11, 1961, at the Bellevue-Stratford Hotel, Philadelphia, Pa.

Ten copies of the abstract, of not more than 800 words, are required. It should include the title of the paper (not to exceed 50 letters, including spaces), the author's name, position and affiliation. In the case of more than one author, please indicate who will present the paper. Ten copies of a biographical sketch (suitable for publication in the PROCEEDINGS) of each author must accompany the abstract.

Authors will be notified of acceptance by June 27, 1960. Final papers will be due October 10, 1960. Submit abstracts and biographical sketches to R. E. Kuehn, IBM Owego, Owego, N. Y.

NBS PREPARES BIBLIOGRAPHY ON RADIO PROPAGATION

In the past few years the Central Radio Propagation Laboratory has been engaged in preparing several bibliographies on tropospheric propagation of UHF, VHF, and SHF radio waves. It is believed that these bibliographies have presented a comprehensive listing of the pertinent literature concerning tropospheric propagation up through 1958.

Because of the favorable reception of the previous bibliographies, and to fill a long-felt need, it has been decided to extend the scope of this bibliography to include all fields of radio propagation.

Since this is an undertaking of considerable proportions, it would be greatly appreciated if any interested reader would forward a list of pertinent references in radio propagation, radio astronomy, radio properties of the ionosphere, etc., to the editor: Malcolm Rigby, Editor, Meteorological Abstracts and Bibliography, P. O. Box 1736, Washington 13, D. C.

Calendar of Coming Events and Authors' Deadlines*

(Continued from page 14A)

Chicago Spring Conf. on Broadcast and Television Receivers, Graemere Hotel, Chicago, Ill., June 20–21.

Conf. on Standards and Electronic Measurements, NBS Boulder Labs., Boulder, Colo., June 22–24.

Workshop on Solid State Electronics, Purdue Univ., Lafayette, Ind., June 23–24.

Natl. Conv. on Mil. Elec., Sheraton Park Hotel, Washington, D. C., June 27–29.

Cong. Intl. Federation of Automatic Control, Moscow, USSR, June 25–July 9.

Int'l Conf. on Electrical Engrg. Education, Sagamore Conf. Center, Syracuse Univ., Syracuse, N. Y., Jul.

7th Ann. Symp. on Computers and Data Processing, Stanley Hotel, Estes Park, Colo., July 28–29.

4th Global Communications Symp., Hotel Statler, Washington, D. C., Aug. 1–3.

WESCON, Los Angeles Mem. Sports Arena, Los Angeles, Calif., Aug. 23–26, (DL*: May 1, R. G. Leitner, WESCON Bus. Office, 1435 So. La Cugna Blvd., Los Angeles 35, Calif.)

URSI 13th Gen. Assembly, Univ. of London, London, Eng., Sept. 5–15.

Joint Automatic Control Conf., M.I.T., Cambridge, Mass., Sept. 7–9.

Space Electronics and Telemetry Conv. and Symp., Shoreham Hotel, Washington, D.C., Sept. 19–22.

Industrial Elec. Symp., Sheraton Cleveland Hotel, Cleveland, Ohio, Sept. 21–22.

Sixth Natl. Communications Symp., Hotel Utica and Utica Municipal Aud., Utica, N. Y., Oct. 3–5. (DL*: June 1, B. H. Baldridge, 25 Bolton Rd., New Hartford, N. Y.)

Natl. Elec. Conf., Hotel Sherman, Chicago, Ill., Oct. 10–12. (DL*: May 1960 Prof. T. F. Jones, Jr., School of E.E., Purdue Univ., Lafayette, Ind.)

Symp. on Space Navigation, Deshler-Hilton Hotel, Columbus, Ohio, Oct. 19–21.

East Coast Conf. on Aero & Nav. Elec., Baltimore, Md., Oct. 24–26.

5th Ann. Conf. on Nonlinear Magnetics and Magnetic Amplifiers, Bellevue-Stratford Hotel, Philadelphia, Pa.

Electron Devices Mtg., Hotel Shoreham, Washington, D. C., Oct. 27–29.

13th Ann. Conf. on Elec. Tech. in Med. and Bio., Sheraton Park Hotel, Washington, D. C., Oct. 31, Nov. 1–2.

Radio Fall Mtg., Hotel Syracuse, Syracuse, N. Y., Oct. 31, Nov. 1–2.

Mid-Amer. Elec. Conv., Hotel Muehlebach, Kansas City, Mo., Nov. 15–16.

1960 NEREM (Northeast Electronics Res. & Engrg. Mtg.), Boston, Mass., Nov. 15–17.

PGVC Ann. Mtg., Sheraton Hotel, Philadelphia, Pa., Dec. 1–2.

Eastern Joint Computer Conf., New Yorker Hotel, New York, N.Y., Dec.

* DL = Deadline for submitting abstracts.

VLF TRANSMISSIONS BEGUN BY U. S. NAVAL OBSERVATORY

The Navy Department announces that Naval Radio Station NBA at Balboa, Panama Canal Zone has begun transmitting precise time signals and constant frequency on VLF (Very Low Frequency), 18 kilocycles per second. At present the signals are transmitted continuously from 0800 to 1600 Eastern Standard Time Monday through Friday. The periods of transmission will be lengthened later as the need arises.

This service was inaugurated in order to meet the needs of the Navy for precise time signals and constant frequency, and to provide means for accurate timing needed in satellite tracking stations spread over the globe.

Experiments conducted by the U. S. Naval Observatory and the Royal Greenwich Observatory in England have shown that time signals transmitted in the very low frequency part of the radio frequency spectrum, such as the 16 kilocycles per second of Station GBR at Rugby, England, and the 18 kc used at the high power transmitter at station NBA in the Panama Canal Zone, can be received over long distances to an accuracy of five ten-thousandths of a second. Recent experiments conducted by the Naval Research Laboratory indicate that an accuracy of time measurement of one ten-thousandth of a second might be achieved. The Naval Observatory, Naval Research Laboratory, and Naval Communications are conducting experiments to improve the accuracy of the service.

Atomic clocks of the cesium-beam type are used to measure the frequency of the transmissions and to maintain the frequency constant to about 1 part in 10 billion. The frequency of cesium used is 9 192 631 770 cycles per second. This experimental value was determined jointly by the U. S. Naval Observatory, Washington, and the National Physical Laboratory, Teddington, England.

Additional details of the NBA broadcasts are contained in Time Service Notices Numbers 6, 7, and 8 of the U. S. Naval Observatory. Further information may be obtained by writing to the Superintendent.

OPTICAL SOCIETY OF AMERICA TRANSLATES RUSSIAN JOURNAL

The Optical Society of America has announced the translation of *Optika I Spektroskopiya* (*Optics and Spectroscopy*) beginning with the January, 1959 issue. This leading scientific journal of the USSR Academy of Sciences publishes the work of Russian scientists in all branches of optics and spectroscopy, including x-ray, ultraviolet, visible, infrared and microwave, thin layer optics, filters, detectors, diffraction gratings, electroluminescence, thermal radiation backgrounds, infrared polarizers, and their other applications in science and industry.

Optics and Spectroscopy is available free to all members of the Optical Society of America as part of their membership privileges, and also to all subscribers to the *Journal of the Optical Society of America* who are not members of the Society. Membership dues, including both *Optics and Spectroscopy* and the *Journal of the Optical Society of America*, are $13.00 per year. Write to Dr. Mary E. Warga, Executive Secretary, Optical Society of America, 1155 Sixteenth St., N.W., Washington, D. C. for the membership application form. Nonmember subscriptions, which include both of the above journals, are $25.00 per year. Subscriptions should be sent directly to the American Institute of Physics, 335 E. 45 St., New York 17, N. Y.

ARMY MARS TECHNICAL NET ANNOUNCES APRIL SPEAKERS

Continuing with its mission of disseminating technical knowledge by radio communication, the First U. S. Army MARS SSB Technical Net announces its speaker program for April. The net operates each Wednesday evening at 9 P.M. EST on 4030 kc upper sideband.

Arrangements have been made by Ted Mathieson, A4FJ, the state MARS Director of Virginia, to use First Army tapes in setting up a Second Army Technical Net with its nucleus around the Washington D. C. area.

Speakers for April include:

April 6 "Filter Design and Applications," J. L. Prather, Instructor, Radio Div., USASCS, Fort Monmouth, N. J.
April 13 "New Semi-Conductors for High Frequency Circuits," W. A. McCarthy, Chief Applications Engineer, Semi-Conductor Div., Raytheon Mfg. Co., Boston, Mass.
April 20 "Modern Trends in Electronic Instrumentation," W. A. Knoop, Jr., Partner, Gawler-Knoop Co., Roselle, N. J.
April 26 "Tacan and Similar Aircraft Navigation Systems," W. Loebel, Project Engineer, Olympic Radio and TV Division of the Siegler Corp., Long Island City, N. Y.

OBITUARIES

Philip R. Coursey (A'17)(L) died recently at the age of 67.

Born in 1892 in Wood Green, Middlesex, England, he received the B.S. degree, with honors, in engineering from University College, London, in 1913. After graduation, he was Professorial Assistant in the Electrical Engineering Department and Research Laboratory at University College, lecturing and doing research work in electrical engineering and radiotelegraphy. In 1912 he became a consulting engineer for wireless telegraphy and related fields to the Dubilier Electrical Syndicate, Ltd., London. At the time of his retirement two years ago he was Chief Engineer of Dubilier Condenser Co., London, England.

Mr. Coursey was a Fellow of the Physical Society of London, a member of the Wireless Society of London, and a member of the IEE in England. He was the author of several technical papers.

George Morton Cummings (A'32–M'46–SM'53), former chairman of the St. Louis, Mo., Section of the IRE, died recently at the age of 64.

Born March 20, 1895 in Sedalia, Mo., he attended grade school and high school there, and later attended Washington University Night School. From 1912 to 1915 he was employed by Union Electric Light and Power Co., and for a year after that he worked for the Wagner Electric Corp. In 1916 he began working for Southwestern Bell Telephone Co., in St. Louis. He was employed in the Engineering Department for many years, having been appointed Demonstrations Engineer for several states in 1951. In this capacity he supervised operation and maintenance of equipment used in exhibits and developed and designed new equipment.

Mr. Cummings served the St. Louis Section of the IRE in various capacities, as Vice-Chairman, Secretary-Treasurer, Program Chairman and Chairman of the Nominations Committee. In 1948 he was elected Chairman of the Section.

Dr. D. O. McCoy (A'46–SM'56–F'59), Chairman of the Cedar Rapids Section of the IRE, died recently at the age of 48.

D. O. McCoy

He was born March 18, 1911 in LaPorte City, Iowa. His formal academic preparation was done at the Iowa State University, where he received the B.S. degree in Mechanical Engineering in 1934, the M.S. in Physics in 1936, and the Ph.D. in Applied Physics in 1938. He contributed to the application of radio to Naval aircraft systems through his research at the Naval Research Laboratory from 1938 to 1947. He served the Laboratory as head of the Research Section of the Airborne Radio Division and later head of the Radar Section of Radio Division III. In 1947 he joined the Research Division of the Collins Radio Company, where his contributions to a number of fields were numerous and significant. Among his many activities was the direction of research and development in the fields of radar, electronic countermeasures, Doppler and phase-locked receiver techniques, radio astronomy, radio-celestial navigation, antennas, and mechanical engineering. He served on the RTCA subcommittee responsible for the study of the distance measuring system (DME) to be recommended for civil use. He was awarded the IRE Fellow Award for his guidance of the research and development leading to the radio sextant, an all-weather navigation system which utilizes the radio emission of the sun and moon.

Dr. McCoy was a member of Pi Mu Epsilon, Sigma Xi, the American Physical Society, and the Institute of Navigation.

ABOUT WATERLOO . . .

Shortly after Waterloo, the Duke of Wellington received a letter, postmarked St. Helena. It was from Napoleon. It read: "Excellency: I was amused to hear your recent remark that 'The Battle of Waterloo was won on the playing fields of Eton.' To have won an engagement in Belgium from a field in England, you must have been further back of the battle lines than I thought.

*"The real reasons for my defeat were two, and Eton was neither. In the first place, the radar broke down for two hours in the heat of battle. Not even a Napoleon can be expected to make radar work without Bomac tubes.**

"But I might easily have defeated you, faulty tubes and all, had I not been persuaded to partake of a bottle of Scotch on the evening before the battle. I have reason to suspect my drink was tainted. At any rate, on the day of Waterloo, I did not display my usual energy and decisiveness.

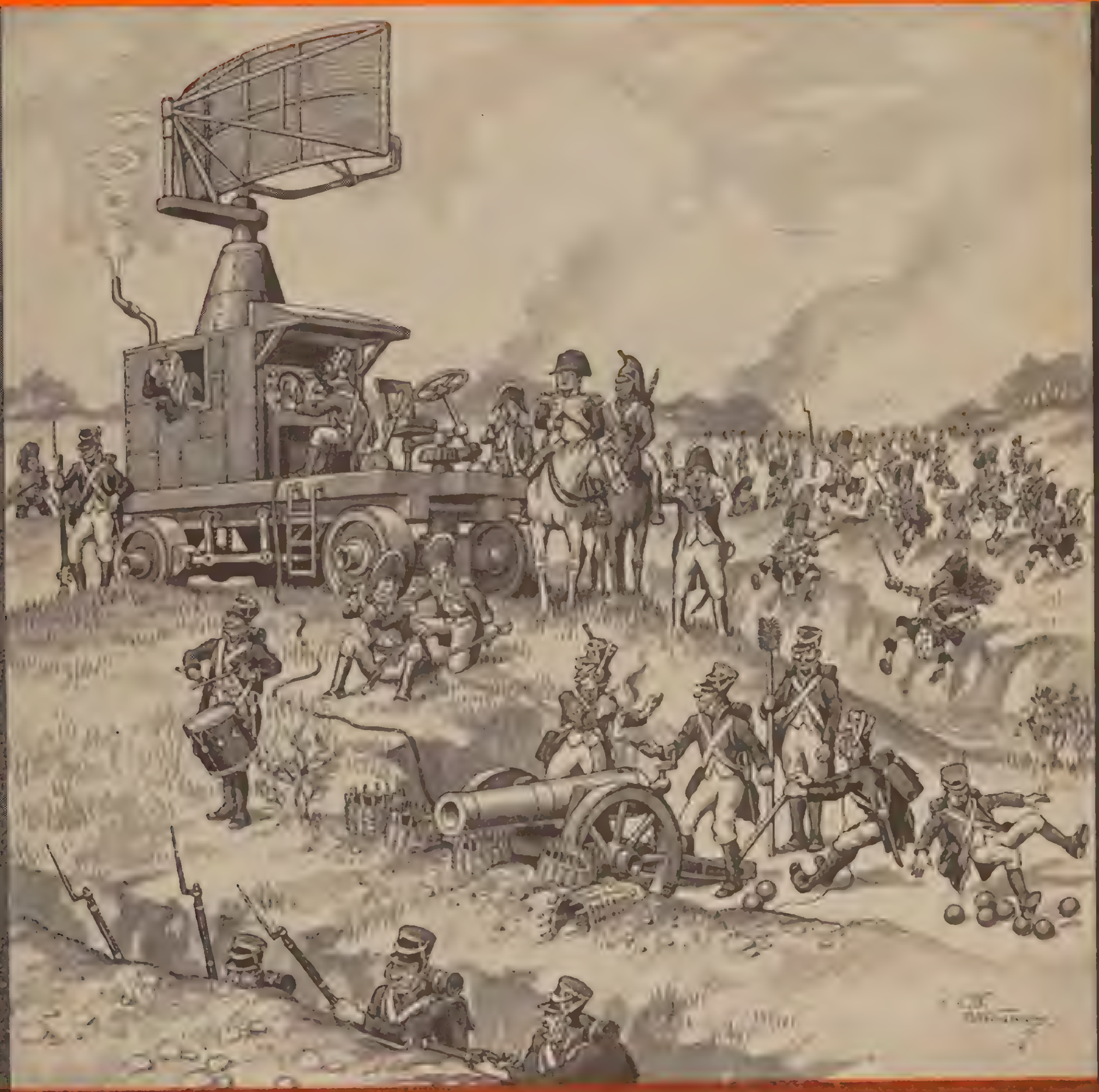
"It appears, in short, that you owe the battle to a bottle. (Signed,) N."

The Emperor received a brief reply by return boat. It read: "Excellency: In view of the fact that your loss at Waterloo appears to have been less a matter of Eton than of Drinking, I am withdrawing my original statement. I have released the following in its place, which I here submit for your approval:

'You can mix Scotch and Water
And Water and Scotch
But don't whatever you do
Make the mistake Napoleon did,
And mix Scotch and Waterloo.'

(Signed,) Wellington."

No. 19 of a series . . . **BOMAC LOOKS AT RADAR THROUGH THE AGES**



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1960 IRE INTERNATIONAL CONVENTION RECORD

The IRE International Convention Record, containing all available Convention papers, will be published in ten parts in July, 1960.

Professional Group members are entitled to purchase the Part sponsored by the Professional Group to which they belong at the special PG rate indicated below. Other parts may be purchased at the IRE member rate.

IRE members may purchase any part at the IRE member rate. However, if a member applies for membership in the appropriate Professional Group at the same time that he places his order, he will be entitled to the PG rate.

Nonmembers and libraries may place orders at the nonmember and library rates, respectively. Individuals who apply for IRE membership at the time they place their orders are entitled to the IRE member rate.

Subscription agencies are entitled to the library rate.

Clip out the order form and return it, with remittance, to the Institute of Radio Engineers, Inc., 1 East 79 St., New York 21, N. Y. In ordering, be sure to refer to the proper columns for subjects and prices.

Part	Sessions	Subject and Sponsoring IRE Professional Group	Prices for Members of Sponsoring Professional Group (PG), IRE Members (M), Libraries and Sub. Agencies (L), and Nonmembers (NM)			
			PG	M	L	NM
1	38, 46, 53	Antennas & Propagation	$0.70	$1.05	$2.80	$3.50
2	33, 40, 41, 48, 49	Circuit Theory Electronic Computers	1.00	1.50	4.00	5.00
3	8, 16, 23, 32, 39	Electron Devices Microwave Theory & Techniques	1.00	1.50	4.00	5.00
4	1, 9, 17, 25	Automatic Control Information Theory	0.80	1.20	3.20	4.00
5	24, 28, 29, 30, 37, 44, 50	Communications Systems Space Electronics & Telemetry	1.20	1.80	4.80	6.00
6	7, 18, 22, 27, 31, 34, 35, 42	Component Parts Industrial Electronics Production Techniques Reliability and Quality Control Ultrasonics Engineering	1.40	2.10	5.60	7.00
7	11, 12, 19, 20, 26, 36	Audio Broadcast & Television Receivers Broadcasting	1.00	1.50	4.00	5.00
8	4, 6, 15, 43, 51, 52	Aeronautical & Navigational Electronics Radio Frequency Interférence Vehicular Communications Military Electronics	1.00	1.50	4.00	5.00
9	2, 10, 14, 21, 47, 54	Medical Electronics Nuclear Science Instrumentation	1.00	1.50	4.00	5.00
10	3, 5, 13, 45	Engineering Writing & Speech Engineering Management Human Factors in Electronics	0.80	1.20	3.20	4.00
		Complete Set (10 parts)	$10.00	$15.00	$40.00	$50.00

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High input impedance (better than 1 meg-ohm).

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Low noise-voltage, referred to shorted input.

C

↓VS-66A→	Parameter	Z Source	←VS-68A ↓
0 to 40, db, 5 steps	Gain	—	10 to 80 db, 8 steps
10 meg	Z_{Input}	—	selectable 10 k or 10 meg
20 cps to 2 mc	Freq. Rg.	—	20 cps ot 180 kc
0.7 uV RMS	$e_{N\text{-}in}$, B=10 kc	0 ohms	0.2 uV, 10k input & 1.4 uV, 10 meg input
0.75 uV RMS	"	100 ohms	0.3 uV, 10k input & 1.5 uV, 10 meg input
0.8 uV RMS	"	500 ohms	0.8 uV, 10k input & 1.6 uV, 10 meg input
0.85 uV RMS	"	1 k	1.3 uV, 10k input & 1.7 uV, 10 meg input
1.9 uV RMS	"	10 k	4.2 uV, 10k input & 3.6 uV, 10 meg input
5.5 uV RMS	"	100 k	— — — 11.0 uV, 10 meg input
10 uV RMS	"	1 meg	— — — 20.0 uV, 10 meg input

The three amplifier characteristics illustrated (A, B and C) are often considered contradictory, even irreconcilable. True, there are amplifiers which exhibit low-noise voltage, referred to the shorted input terminals. Fact is, our VS-64A still holds the record in this field — less than 0.5 mu V RMS over a 60 kc pass band. Also, there are many high input impedance amplifiers. But never before have low-noise voltage characteristics and high input impedance been combined with a highly incompatible third stipulation: tolerance of high source impedance, without spoilage of premium shorted-input noise performance, by insertion of a comparatively large source impedance.

Two new Millivac low-noise amplifiers — the VS-66A and VS-68A — *combine all 3* of these most desirable characteristics to meet the demands of the Space Age for extended communications and control ranges.

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is our
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1960 Spring Technical Conference

Hotel Alms, Cincinnati, Ohio, April 12–13, 1960

Tuesday Morning, April 12

Opening Address: *F. C. Reith, President, Crosley Div., and Vice President of Avco Corp., Cincinnati, Ohio.*

Session 1A

Panel: Missile and Space Vehicle Reentry.

Chairman: *Major General M. C. Demler, Assistant Deputy Chief of Staff, USAF; Director, Res. and Dev.*

"The Theory of Hypersonic Re-entry," *Dr. R. Hermann, University of Minnesota, Director of Rosemount Research Lab., Minneapolis, Minn.*

"The Engineering Approaches to the Re-entry Problem," *Dr. F. R. Ridell, Avco Corp., Research and Advanced Development Div., Wilmington, Mass.*

"Plasma Sheet Characteristics About a Hypersonic Vehicle," *Dr. H. A. Lew, General Elec. Co., Missile and Space Systems Div., Philadelphia, Pa. and V. A. Langelo, Space-Science Labs., Moorestown, N. J.*

"Performance Capabilities of Lifting Hypervelocity Vehicles," *Dr. R. B. Hildenbrand, Advanced Systems Research, Aero-Space Div., Boeing Airplane Co., Seattle, Wash.*

Session 1B

Panel: Can Computers Out-Think People?

Chairman: *J. C. Elms, Vice President and General Manager, Avco Corp., Crosley Div., Cincinnati, Ohio.*

"One Plus One is Not Necessarily Two—A Tutorial Paper on Number Systems," *A. C. Cook, Application Engineer, General Electric Co., Cincinnati, Ohio.*

"Resistor-Transistor Logic in a Large Scale Digital Computer," *J. N. Conway, General Precision Equipment Corp., Librascope Div., Burbank, Calif.*

"An All-Transistor Control Computer for Ballistic Missiles," *W. E. Lane, The Martin Co., Orlando, Fla.*

"A Macro-Module Computer," *S. Schneider, The Burroughs Corp., Paoli, Pa.*

Tuesday Afternoon—Session 2A

Panel: Why Will Tunnel Diodes Revolutionize Electronics?

Chairman: *Dr. G. Bruck, Senior Staff Scientist, Avco Corp., Crosley Div., Cincinnati, Ohio.*

"A Report on the State of the Art" *E. O. Johnson, RCA, Semiconductor and Materials Div., Somerville, N. J.*

Panel Discussion: *L. Cuccia, RCA, Harrison, N. J., N. J. Golden, Hoffman Electronics Corp., El Monte, Calif.; Dr. C. S. Kim, General Electric Co., Syracuse, N. Y.; R. Pritchard, Texas Instruments, Inc., Dallas, Texas; Dr. A. Pucel, Raytheon Co., Waltham, Mass., and Dr. E. R. Steele, Hughes Aircraft Corp., Newport Beach, Calif.*

Session 2B

Panel: The Use of Data Processing in Bio-Electronics.

Chairman: *Colonel J. P. Stapp, M.D., Director of the Aero-Space Medical Lab., WADD, USAF ARDC; Past President of the American Rocket Society.*

"Selectively Monitoring Physiological Data," *M. A. McLennon, Chief, Bio-Electronics Section, Bio-Physics Branch, Aero-Space Medical Lab., WADD.*

"Implications of Some Recent Work with Skin Resistance," *Captain V. H. Thaler, USAF (MSC), Aero-Space Medical Lab., WADD.*

"A Biological Dynamic Energy Transducer," *Dr. J. R. Mundie, M.D., Bio-Acoustics Branch, Aero-Space Medical Lab., WADD.*

"The Contributions of Biology to Electronic Design," *Major J. E. Steele, M.D., USAF, MC.*

Wednesday Morning, April 13

Session 3A

Panel: Electronic Data Processing Comes of Age (Building Blocks).

Chairman: *R. G. Counihan, Manager, Micro-Machine Development, IBM Corp., Kingston, N. Y.*

"Magnetic Tape Techniques in Data Processing," *B. Haslam, Avco Corp., Crosley Div., Electronics Research Labs., Boston, Mass.*

"High Speed Logic Using Low-Cost Mesa Transistors," *R. Lohman, RCA, Semiconductor and Materials Div., Somerville, N. J.*

"A Switching Applicaiton for PN-PN Transistors in Data Processing Machines," *P. A. Bunyar, IBM Corp., Kingston, N. Y.*

IBM Color Film: "The X-15-Man into Space."

"Circuit Techniques Used in the LARC Computer," *L. M. Spandorfer, Sperry Rand Corp., Remington Rand Univac Div., Philadelphia, Pa.*

Session 3B

Panel: Objectives and Accomplishments of the International Geophysical Year.

Chairman: *Dr. J. Kaplan, University of California, Los Angeles; Chairman of the U. S. National Committee of the 1957–58 IGY, National Academy of Sciences.*

"The Use of Rockets and Satellites as Tools to Aero-Space Research During the IGY," *Dr. R. W. Porter, General Electric Co., Corporate Headquarters, New York, N. Y.*

"Towards Our Knowledge of the Earth," *Dr. G. P. Woollard, Department of Geology, University of Wisconsin, Madison, Wis.*

"Physical Phenomena of the Cis-Lunar Space," *Dr. F. Johnson, Lockheed Aircraft Corp., Palo Alto, Calif.*

"Oceanography and the IGY," *Dr. R. R. Revelle, Scripps Institute of Oceanography..*

Luncheon Speaker: *Major General M. C. Demler; Assistant Deputy Chief of Staff, USAF; Director, Res. and Dev.*

Wednesday Afternoon—Session 4A

Panel: Inertial Guidance for Missile and Space Vehicle Applications.

Chairman: *Dr. C. S. Draper, Director, Instrumentation Lab., M.I.T., Cambridge, Mass., Chairman, U. S. Inventor's Council.*

"Problems of Precision Inertial Velocity Measurements," *Dr. J. H. Slater, Autonetics Div., American Aviation, Inc., Downey, Calif.*

"Inertially Instrumented Interplanetary Guidance," *H. Winter, Bell Aircraft Corp., Avionics Div., Inertial Development Labs., Niagara Falls, N. Y.*

"The Application of Inertial Guidance Techniques to Stabilization in Orbit," *J. J. Klien, Lockheed Aircraft Corp., Missile Systems Div., Sunnyvale, Calif.*

"Inertial Guidance—Present and Future," *R. C. Berendsen, General Electric Co., Defense Electronics Div., Pittsfield, Mass.*

"Inertially Derived Rate of Descent Measuring System," *R. K. Smyth, J. W. Montooth, and D. D. Farnum, Autonetics Div., North American Aviation, Inc., Downey, Calif.*

Session 4B

Panel: Electronic Data Processing Comes of Age (Systems).

Chairman: *T. H. Bonn, Senior Staff Scientist, Sperry Rand Corp., Remington Rand Univac Div., Philadelphia, Pa.*

"The 117L Program," *M. Ehlers, Beckman Instrument Corp., Chicago, Ill.*

"Electronic Data Processing at the Atlantic Missile Range with Emphasis on the Azusa Tracking System," *R. J. Pepple, RCA Data Reduction Center, AF Missile Test Center, Cape Canaveral, Fla.*

"A Radar Simulator Design Using Binary Digital Techniques," *Dr. R. J. McNair, Avco Corp., Crosley Div., Cincinnati, Ohio.*

"COED—A Device for the Simulation of Man/Machine Operations," *R. H. Johnson, Bendix Aviation Corp., Systems Div., Ann Arbor, Mich.*

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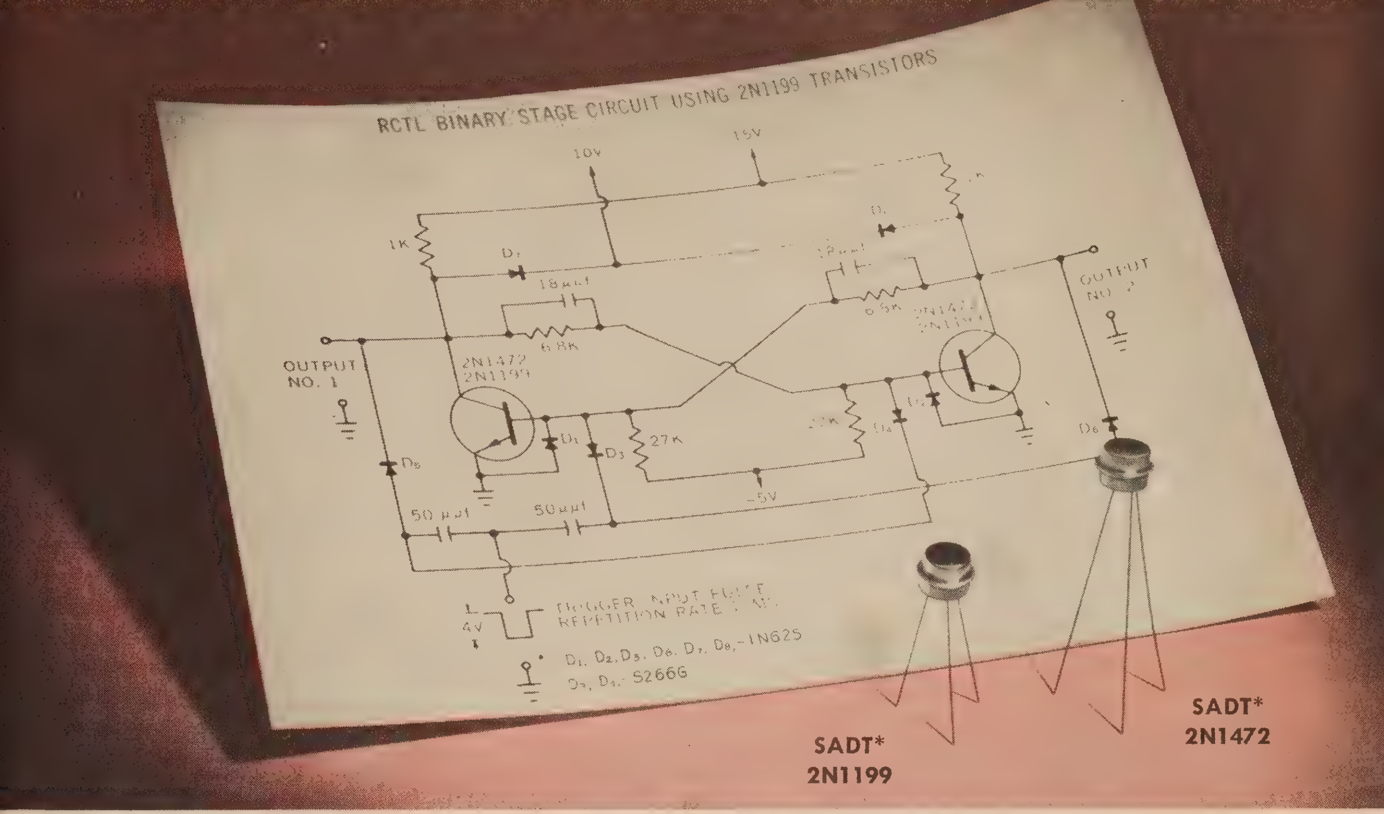
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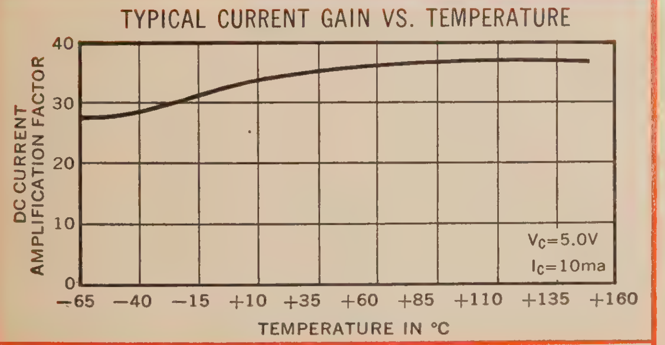
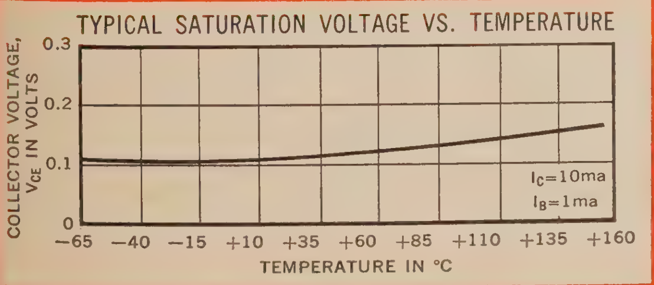
D3
D5
D6
27K
50μμf
50μμf
-5V
TRIGGER INPUT PULSE REPETITION RATE 1 MC
4V
D1, D2, D5, D6, D7, D8, - 1N625
D3, D4, - S266G
SADT* 2N1199
SADT* 2N1472

PHILCO HIGH FREQUENCY NPN SILICON TRANSISTORS OFFER EXCEPTIONALLY LOW SATURATION VOLTAGE



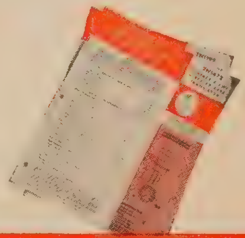


The high frequency response, together with the very low saturation voltage of these silicon Surface Alloy Diffused-base Transistors (typically 0.125 V), permits practical design of 5 mc pulse circuits, using conventional saturated switching configurations. With non-saturating techniques, pulse rates as high as 30 mc are obtainable. The typical switching circuit shown above will operate satisfactorily at trigger pulse rates up to 15 mc. When triggered with a 4-volt pulse at a 10 mc rate, the rise time will be typically less than 24 mμsec over a temperature range of −60°C to +130°C. The typical fall time will be less than 36 mμsec over the same temperature range.

Both of these transistors have demonstrated consistently more stable characteristics over a wide temperature range than any other silicon transistors available. Both meet the environmental and life test requirements of MIL-S-19500B.

NEW, MORE COMPLETE DATA SHEETS

The new data sheets on these transistors, for the first time, provide the designer with complete information upon which he may predict switching speeds in any circuit. They also contain the full military environmental and life test specifications, in accordance with MIL-S-19500B. Copies are available on request. Write Dept. IR-460.



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Third Annual Conference on Automatic Techniques

SHERATON CLEVELAND HOTEL, CLEVELAND, OHIO, APRIL 18–19, 1960

For the third consecutive year, the American Institute of Electrical Engineers, the American Society of Mechanical Engineers, and the Institute of Radio Engineers have joined together to co-sponsor the Joint Automatic Techniques Conference.

The increasing complexity in all specialized fields of endeavor makes it difficult to identify and understand the unifying theme of all modern technologies—automatic techniques. As it is envisioned, this conference draws upon the experiences of a variety of industries, obtaining both a general outline of certain problems that have confronted the industries and a discussion of the automatic techniques and the reasoning that was applied in solving the problems. Dealing broadly with techniques that have proved successful in solving practical problems, the conference appeal cuts across both industry classifications and job function categories.

April 18

Session 1—Automatic Manufacturing

"Metal Forming Under Electronic Sequencing," *E. V. Crane, Chief of Special Engineering, E. W. Bliss Co., Canton, Ohio.*

"Automatic Assembly," *J. F. Stoltz, Dept. Chief., Development Engineering, Hawthorne Works, Western Electric Co., Chicago, Ill.*

"Numerical Control Developments," *R. G. Chamberlain, Supervisor Programming, Giddings & Lewis Machine Tool. Co., Fond du Lac, Wis.*

Session 2—Automatic Inspection and Quality Assurance

"Automatic Gaging," *H. L. Boppel, Mgr. Autometrology Div., Sheffield Corp., Dayton, Ohio.*

"Production Line Testing Programmed by Punched Cards," *R. E. Wendt, Jr., Manager, Advanced Manufacturing Techniques, Headquarters Manufacturing Lab., Westinghouse Electric Corp., Pittsburgh, Pa.*

"Airframe Structural Integrity Testing," *R. L. Bondurant, Project Engineer, and D. W. Jackson, Unit Chief, Wright Air Development Center, Wright-Patterson AFB, Ohio.*

April 19

Session 3—Computer Control for Utility and Process Industries

"Operational Information System at Sterlington Steam Electric Station," *J. A. Reine, Jr., Head, Electrical Maintenance Dept., Sterlington Steam Electric Station, Sterlington, La.*

"Problems Encountered and Solved in Starting of Computer Controlled Systems," *W. F. Aiken, Project Engineering Mgr., Thompson-Ramo-Wooldridge Products Co., Los Angeles, Calif.*

"User-Supplier Relationship in Automating a Steel Rolling Mill," *C. W. Burdick, Electrical Engr., Engineering & Construction Div., Lukens Steel Co., Coatesville, Pa.; N. L. Weckstein, Equipment Engineering, Industry Control Dept., General Electric Co., Raonoke, Va.; and R. A. Hamilton, Application Engr., General Electric Co., Philadelphia, Pa.*

Session 4—Automatic Warehousing

"Automatic Baggage Handling," *H. C. Warrington, United Air Lines, Denver, Colo.*

"Automation As Applied to Book Warehousing and Shipping," *J. B. Bennett, Jr., Vice President, Secretary, and General Manager, The Macmillan Co., New York, N. Y.*

"Automatic Palletization Facilities at C and H Sugar Refining Corp., "*D. C. Gutleben, Mech. Engr., California and Hawaiian Sugar Refining Corp., Crockett, Calif.*

Tenth Symposium on Active Networks and Feedback Systems

ENGINEERING SOCIETIES BUILDING, NEW YORK, N. Y., APRIL 19–21, 1960

The tenth international symposium organized by the Polytechnic Institute of Brooklyn's Microwave Research Institute will be held on April 19–21, 1960 in the Auditorium of the Engineering Societies Building (33 W. 39 St.) New York, N. Y. This Symposium on Active Networks and Feedback Systems is cosponsored by the Professional Group on Circuit Theory of the IRE. The support of the Air Force Office of Scientific Research, the Office of Naval Research and the U. S. Army Signal Research and Development Laboratory makes it possible to hold this event without any charge for admission or registration.

This series of annual symposia has been attended by as many as 940 Scientists and Engineers in past years. Previous topics have included: Nonlinear Circuit Analysis (1953 and 1956), Modern Network Synthesis (1952 and 1955), Information Networks (1954) and four others on Millimeter Waves (1959), Microwave Techniques, Solid State Phenomena and Electronic Waveguides. As in the past, authorities will summarize the present state of the art and recent outstanding advances will be presented by research workers from university, industrial and government laboratories throughout the world.

Abstracts of all papers, a detailed program and registration form are available from The Microwave Research Institute, Polytechnic Institute of Brooklyn, 55 Johnson St., Brooklyn 1, N. Y.

Tuesday Morning April 19

The State of the Art and Future Trends

"Feedback—The History of an Idea," *H. W. Bode, Bell Telephone Labs., Inc.*

"Active Networks—Past, Present and Future," *J. G. Linvill, Stanford University.*

"Network Synthesis with Negative Resistors," *H. J. Carlin and D. C. Youla, Microwave Research Institute.*

Tuesday Afternoon

Feedback Networks and Systems

"The Methods of Feedback System Synthesis—A Survey," *J. A. Aseltine, Space Technology Labs., Inc.*

"Feedback System Evaluation," *J. G. Truxal and E. Mishkin, Polytechnic Institute of Brooklyn.*

"An Appraisal and Critique of a Class of Adaptive Systems," *I. M. Horowitz, Hughes Research Labs.*

"Feedback Systems with Non-Rational Transfer Function," *A. Papoulis, Polytechnic Institute of Brooklyn, and Institut für Hochfrequenztechnik, Germany.*

"Signal Transmission in Non-Reciprocal Systems," *J. H. Mulligan, Jr., New York University.*

"A New Design Approach for Feedback Amplifiers," *M. S. Ghausi and D. O. Pederson, University of California.*

Wednesday Morning, April 20

Synthesis of Active Networks

"The Use of the Active Lattice to Optimize Transfer Function Sensitivities," *R. E. Thomas, United States Air Force Academy.*

"Necessary and Sufficient Conditions for the Existence of ±R, C Networks," *B. K. Kinariwala, Bell Telephone Labs., Inc.*

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	5 kcs and up	5/8 x 15/16 x 1/2

Weight of all MLP and MHP Microids—approx. .3 ozs. each

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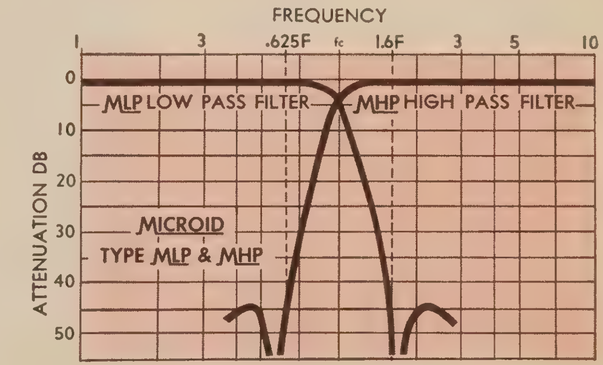

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"Ideal Three-Terminal Active Networks," *A. W. Keen, Lanchester College of Technology, England.*

"Optimum Negative Resistance Amplifiers," *D. C. Youla and L. I. Smilen, Microwave Research Institute.*

"Gain-Bandwidth Performance of Maximally Flat Negative-Conductance Amplifiers," *E. W. Sard, Airbourne Instruments Lab.*

"Synthesis of Wide-Band Amplifiers," *N. DeClaris, Cornell University.*

"High Selective Bandpass Filters Using Negative Resistances," *M. Kawakami, Takeshi Yanagisawa and H. Shibayama, Tokyo Institute of Technology, Japan.*

Wednesday Afternoon

Active Network Concepts

"Physical Realizability of an Active Impedance," *M. Debart, Société Alsacienne de Constructions Mécaniques, France.*

"Generalization of the Frequency-Power Formulas of Manley and Rowe," *P. Penfield, Jr., M.I.T.*

"Bounds on Natural Frequencies of Linear Active Networks," *C. A. Desoer and E. S. Kuh, University of California.*

"Design of Circuits to Tolerate a Range of Transistor Parameters," *P. E. Merritt, Stanford Research Institute.*

"Polytype-Port Active Devices and Networks," *E. E. Loebner, RCA Labs.*

"Topology and Linear Transformation Theory in Active Network Synthesis," *E. A. Guillemin, M.I.T.*

"Formal Realizability of Linear Networks," *Y. Oono, Kyushu University, Japan.*

Thursday Morning, April 21

Time Variable Networks

"Simulation of Orthogonal Functions," *C. V. Jakowatz, General Electric Research Lab.*

"A Modified Form of the Mellin Transform and Its Application to the Optimum Final Value Control Problem," *J. Peschon, Stanford Research Institute.*

"The Synthesis of Models for Time-Varying Linear Systems," *J. B. Cruz, Jr. and M. E. Van Valkenburg, University of Illinois.*

"Periodic Solutions of Nonlinear Differential Systems," *L. Cesari, Purdue University, and Math Res. Group, University of Wisconsin.*

"On the Properties of an Active Time-Variable Network: The Coherent Memory Filter," *J. Capon, Federal Scientific Corp.*

"Acquisition and Tracking Behavior of Phase-Locked Loops," *A. J. Viterbi, Jet Propulsion Lab., California Institute of Technology.*

Thursday Afternoon

Time-Varying Systems

"Linear Time Variable Transducers," *S. Darlington, Bell Telephone Labs., Inc.*

"Perturbation Theory in Time-Varying Systems," *A. Tonning, Norwegian Defence Research Establishment, Norway.*

"Amplification in Nonlinear Reactive Networks," *W. R. Bennett, Bell Telephone Labs., Inc.*

Panel Discussion on Time-Varying Systems; Moderator: *S. Darlington, Bell Telephone Labs., Inc.;* Panel: *W. R. Bennett, L. Cesari, J. A. Ragazzini, A. Tonning and R. J. Schwarz.*

Twelfth Annual SWIRECO

SHAMROCK HILTON HOTEL, HOUSTON, TEXAS, APRIL 20–22, 1960

Wednesday, April 20

Session 1A—Instrumentation I

"The Responsibility of the Sales Engineer," *R. C. McKinney, Allied Components Inc., Dallas, Tex.*

"To Buy—Or To Build—Laboratory Equipment," *D. I. Rummer, University of Kansas, Lawrence.*

"Instrumentation of an Inertial Guidance System," *G. W. Fuller and D. A. Scott, Jr., Chance Vought Aircraft, Dallas, Tex.*

"Analog Troque Control of Rate Sensitive Inertial Components Using a Frequency Modulated, Heterodyne Read-Out System," *E. P. Fitzgerald, Chance Vought Aircraft, Dallas, Tex.*

Session 1B—Neurophysiology and EEG

"A Low Cost Method of Securing Integrated EMG in Real Time," *H. M. Hanish, Litton Industries, Los Angeles, Calif.*

"A Three Channel Electromyograph with Synchronized Slow Motion Photography," *R. W. Vreeland, et al., University of California, Medical Center, San Francisco.*

"An Active Low-Pass Filter for Biological Potential Amplifiers," *G. White, White Instrument Lab., Austin, Tex.*

"Analysis of Neuronal Soma Action Potentials by the Method of Multiple Paired Echoes," *R. M. Morrell, Montreal Neurological Inst., Montreal, P.Q.*

"Short Duration Hormonic Analysis of EEG Data," *E. S. Krendel, Franklin Inst., Philadelphia, Pa.*

Welcoming Luncheon

Speaker: *Dr. R. L. McFarlan, Presiden of IRE.*

Wednesday Afternoon

Session 2A—Instrumentation II

"Automatic Testing of Radio Command Guidance Equipment," *B. C. Hooker, Chance Vought Aircraft, Dallas, Tex.*

"A Digital Timing System for Airborne Application," *G. P. DuBose and C. E. Grubbs, Temco Aircraft, Dallas, Tex.*

Special Bandpass Filters for Instrumentation and Control Systems," *A. N. McGown, Jr., White Instrument Labs., Austin, Tex.*

"A Wide Band Squaring Circuit," *R. Gaertner, Texas Instruments Inc., Dallas, Tex.*

"The Energy Necessary for Exploding Fine Wires Electrically," *S. M. Vakil and D. L. Waidelich, University of Missouri, Columbia.*

Session 2B—Neurophysiology and EEG II

"Signal Theory Applied to the Analysis of Electroencephalograms," *E. Lowenberg, University of Texas, Austin.*

"Period Analysis of the Electroencephalogram," *N. R. Burch, H. E. Childers, and W. A. Spoor, Baylor University College of Medicine, Houston, Tex.*

"Averaging and Correlation Techniques Applied to Neurophysiological Measurements," *H. W. Shipton, State University of Iowa, Iowa City.*

"An Automatic Device to Convert Electroencephalograph Records into Digital Form," *M. G. Saunders, Winnipeg General Hospital, Winnipeg, Man.*

"Expanded Network Concepts for Analyzing Bioelectric Potentials," *B. Saltzberg, Ramo-Wooldridge, Los Angeles, Calif.*

Wednesday Evening

Session 3A—Space Physiological Instrumentation

"Requirements of Physiological Instrumentation for Missile Flight," *W. Greatbatch, Taber Instrument Corp., North Tonawanda, N. Y.*

"An Automatic Physiological Telemetry and Data Conversion System," *C. A. Steinberg, W. E. Sullivan, and J. T. Farrar, Airborne Instrument Labs., Mineola, N. Y.*

Round Table Discussion on Space Medicine.

Thursday Morning, April 21

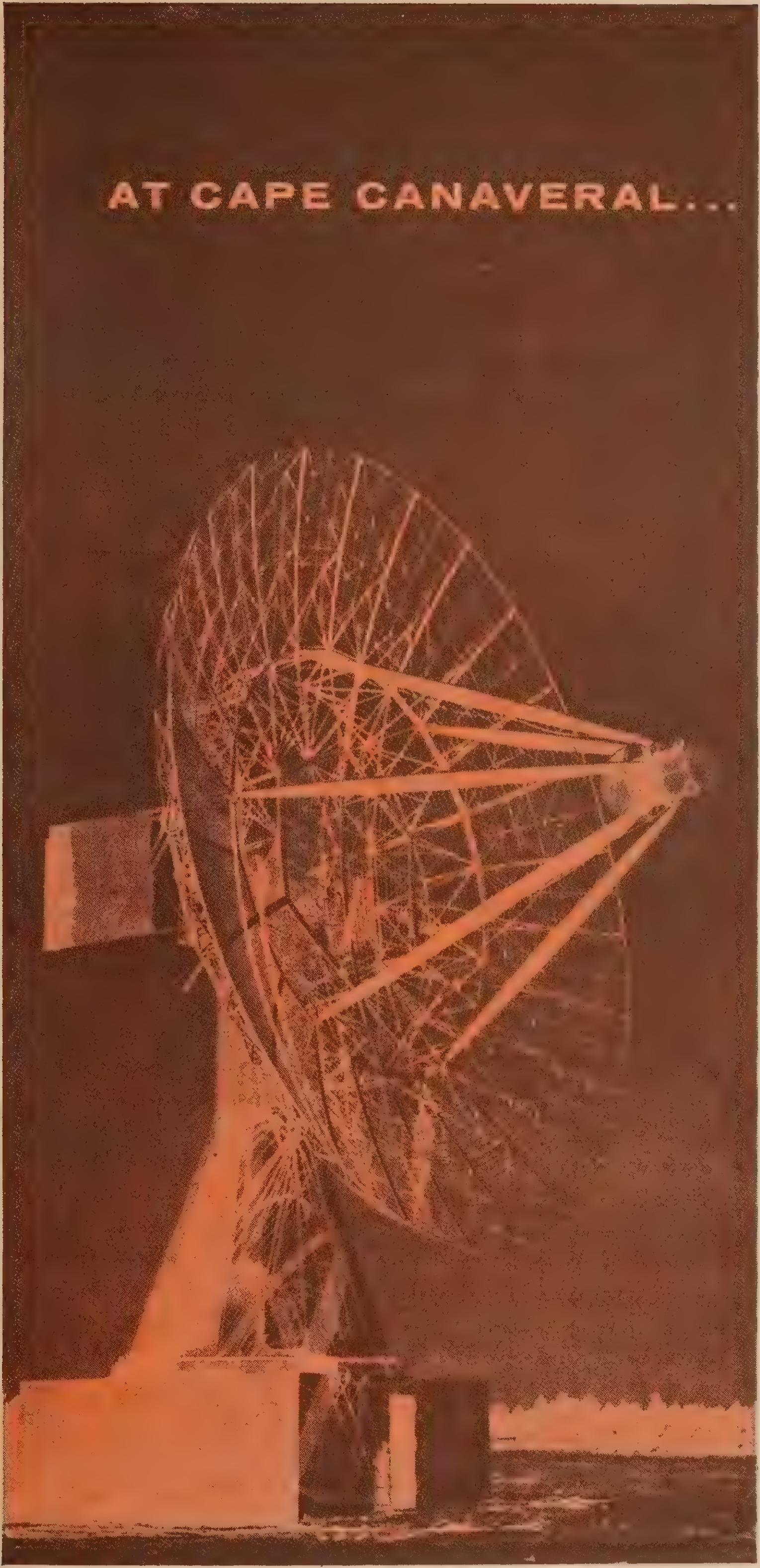
Session 4A—Computers

"Instrumentation of an Analog Seismic Correlator," *L. C. Cummings, Jr. and F. N. Tullos, Humble Oil and Refining Company, Houston,, Tex.*

"A Real Time Auto Correlator," *S. D. Hays, Convair, San Diego, Calif.*

"Description of Rice Institute Computer," *Dr. M. Graham, Rice Inst., Houston, Tex.*

"Engineering Details of Rice Institute Computer Memory," *T. Schutz, Rice Inst., Houston, Tex.*



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Styroflex® coaxial cable has earned an outstanding record for these qualities in a variety of industrial, mass communication and telemetering applications. Perhaps this cable can answer your particular high frequency cable problem. We invite your inquiry.

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"Engineering Details of Rice Institute Computer Control Section," *P. Deck, Rice Inst., Houston, Tex.*

Session 4B—Biophysics I

"An Interpretation of the Effects of Atmospheric Ions on Behavior," *A. H. Fray, General Electric, Ithaca, N. Y.*

"A Non-Dispersive Infrared Gaseous CO_2 Analyzer for Physiological Studies" *L. E. Baker, Rice Inst., Houston, Tex.*

"Digital Print-Out System for Whole Body Scanner," *J. W. Beattie and G. C. Bradt, Sloan-Kittering Inst. for Cancer Research, New York, N. Y.*

"The Use of Flying Spot Scanning Techniques and Medical Research," *L. Hundley and P. O'B. Montgomery, University of Texas Southwest Medical School, Dallas, Tex.*

"An Analog Computer Model for the Study of Electrolyte and Water Flows in the Extracellular and Intracellular Fluids," *W. H. Pace, Jr., Tulane University, New Orleans, La.*

Medical Electronics Luncheon

Speaker: *Dr. H. Strughold, U. S. Air Force School of Medicine, San Antonio, Tex.*

Thursday Afternoon

Session 5A—Semiconductor Materials and Thermoelectricity

"Methods of Characterizing Semiconductor Surfaces," *C. G. Peattie, Texas Instruments Inc., Dallas, Tex.*

"Semiconductor Material Chemistry," *R. E. Johnson, Texas Instruments Inc., Dallas, Tex.*

"Fundamentals of Thermoelectric Power Generation," *T. A. Harwood, Texas Instruments Inc., Dallas, Tex.*

"Thermostating a Thermoelectric Cooler," *R. Marlow, Texas Instruments Inc., Dallas, Tex.*

"Control Circuit for Thermoelectric Devices," *A. R. Orsinger, Texas Instruments Inc., Dallas, Tex.*

Session 5B—Broadcasting

"Transistors in T. V. Receivers," *R. Webster, Texas Instruments Inc., Dallas, Tex.*

"Low Power Television Broadcast Techniques," *M. Zimmerman, Electron Corp., Dallas, Tex.*

"The Ohms-Law Phasor," *L. J. N. duTriel.*

"Directional Antennas for VHF Television Broadcasting," *H. H. Westcott, RCA, Camden, N. J.*

"Propagation Characteristics of High VHF Signals in the Immediate Vicinity of Trees," *Dr. A. H. LaGrove, University of Texas, Austin, Tex.*

Session 5C—Biophysics II

"Electronic and Computer Techniques in the Diagnosis of Cardiovascular Disease," *W. E. Tolles, W. J. Carbery and C. A. Steinberg, Airborne Instruments Lab., Mineola, N. Y.*

"Automation of Total Physiological Sensor Systems; A Reliability and Information Content Study," *B. J. Bittner and W. S. Musgrove, The Kaman Aircraft Corp., Colorado Springs, Colo.*

"Factor Analytic Methods in Medical Research," *L. W. Gaddis and W. B. Michael, University of So. California, Los Angeles.*

Periodogram and Autocorrelogram Estimates of Physiologic Circadian Periodicity by Electronic Computers—Their Use and. Limitations," *F. Halberg, M.D., University of Minnesota Medical School, Minneapolis.*

"The Micro-Coulomb Method of Ozone Measurement," *G. M. Mast, Mast Development Co., Davenport, Iowa.*

Friday Morning, April 22

Session 6A—Transistor Applications

"Thermister Compensation of Transistorized Crystal Oscillators," *O. J. Baltzer, Textran Corp., Austin, Tex.*

"A Transistorized Seismic Amplifier System," *D. Venker, Texas Instruments Inc., Houston, Tex.*

"A Transistor Ferrite Core Energy Storer," *F. M. Crum, Lamar State College of Technology, Beaumont, Tex.*

"Transistor Amplifier Feed-Back Systems," *A. Parker, M.I.T., Lincoln, Lab., Lexington, Mass.*

"A Practical Approach to Transistorized Voltage Regulator Design," *E. Wilson, Texas Instruments Inc., Dallas, Tex.*

Session 6B—Physiology

"The Use of Square-Wave Electromagnetic Flow Meter to Pulse an Electrical Analogy of the Peripheral Arterial System," *M. P. Spencer, Wakeforest College, Winston-Salem, N. C.*

"Odd Problems with the Implanted Electromagnetic Blood Flow Meter: Analysis of Blood Stream Power Loss by Analog Computers and Implanted Flow Meters," *F. Olmsted, Cleveland Clinic, Cleveland, Ohio.*

"Remote Recording of Physiological Responses of Subjects Undergoing Large Amplitude Vertical Accelerations," *E. S. Gordon, Armour Research Found., Chicago, Ill.*

"Electronic Indication of Visual Fixation Point," *E. L. Thomas, Defense Research Board, Toronto, Ont.*

"Acoustic Properties of Isophageal and Artificial Larynx Speech of Laryngectomies," *H. L. Barney, Bell Telephone Lab., Murray Hill, N. J.*

Engineering Education Luncheon

Speaker: *Dr. L. Griffis, Rice Inst., Houston, Tex.*

Friday Afternoon

Session 7A—Communications

"VHF Antenna Development," *T. R. Fouts and J. I. Humphries, Chance Vought Aircraft, Dallas, Tex.*

"Regulus II Missile Program Antenna Systems," *T. R. Fouts and J. I. Humphries, Chance Vought Aircraft, Dallas, Tex.*

"A Retarded Surface Wave Antenna," *E. G. Keiffer, Chance Vought Aircraft, Dallas, Tex.*

"Sequential Detection Techniques in Pulse Communication and Radar," *M. Schwartz, Polytechnic Institute of Brooklyn, Brooklyn, N. Y.*

"System Design of the FAA Airport Surveillance Radar," *F. Simonds, Texas Instruments Inc., Dallas, Tex.*

Session 7B

Tours of medical facilities in the Houston area with inspection of specific equipment and projects.

National Aeronautical Electronics Conference

DAYTON BILTMORE AND PICK-MIAMI HOTELS, DAYTON, OHIO, MAY 2–4, 1960

The Twelfth Annual "National Aeronautical Electronics Conference" (NAECON) will be held on May 2–4, 1960 at the Dayton Biltmore and Pick-Miami Hotels, Dayton, Ohio. The theme of the Conference has been established as "Electronics Probes the Universe." In the light of recent events and those events planned for the new decade, this theme presents a timely background for the 1960 Conference.

The formulation of the papers program was highlighted by two advance actions. First, twenty session topics appropriate to the conference theme were carefully selected. Second, twenty men nationally prominent in the respective session topics were invited to serve as moderators. The session titles and moderators are listed below. These two actions were closely knit by giving each moderator the responsibility for organizing and selecting the four papers that will be presented at his session. Another feature is that several special sessions were arranged to enable "sister" professions to lend a well-

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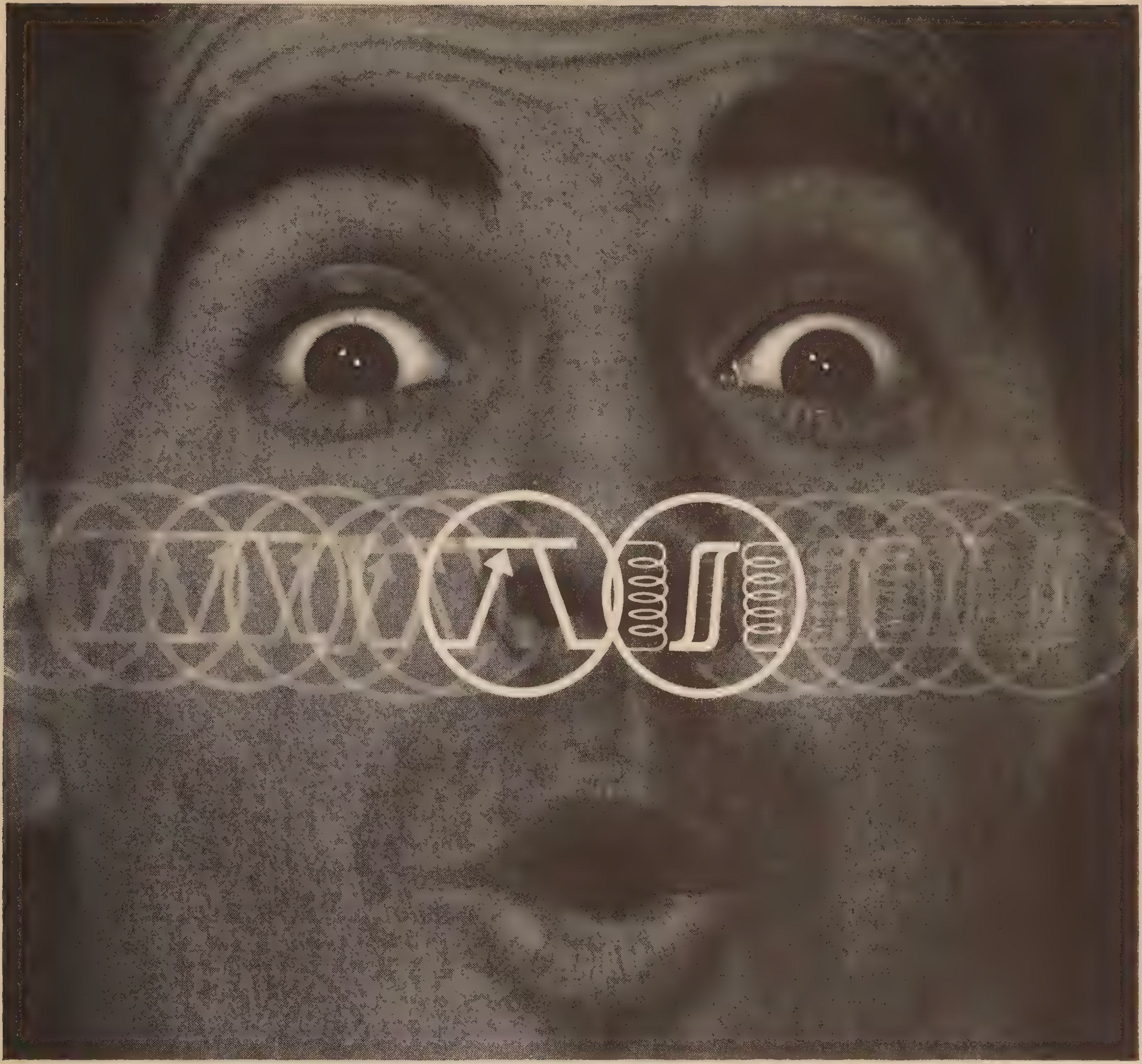

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For instance? The core has multiple isolated windings. Thus you can feed many inputs to control the amplifier. The core also has a square hysteresis loop, and thus acts as a low loss transformer. That means you save power. In addition, the core can store and remember signals—so time delay becomes simple.

There's no need for temperature stabilization, either. The transistor acts only as a low loss, fast, static switch—and in this function it has no peer.

How do you want to use this superb combination? As a switching amplifier—or a linear one? In an oscillator? A power converter (d-c to d-c or d-c to a-c)? You'll have ideas of your own—and if they involve tape wound cores, why not write us? Ours are Performance-Guaranteed. *Magnetics, Inc., Dept. P-81, Butler, Pennsylvania.*

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rounded flavor to the technical program; these sessions are "Scientific Education," "Radio Astronomy," "Electric Propulsion," and "Magnetohydrodynamics."

In addition to the professional sessions, the Conference will also feature a "Student Prize-Paper Session" comprised of college student-authors from Region IV. This new generation of technical people will deliver their papers in the English Room of the Biltmore Hotel on Monday, May 2, 1960, starting at 9 A.M.

Monday Morning, May 2

Session 1—Radio Astronomy

Dr. F. T. Haddock, University of Michigan.

Session 2—Solid State Devices

Dr. I. A. Lesk, Advanced Semiconductor Lab., General Electric Co.

Session 3—Energy Conversion Systems

Dr. A. M. Zarem, President, Electro-Optical Systems, Inc.

Session 4—Ground Support

V. de Biasi, Associate Editor, Space /Aeronautics Magazine.

Monday Afternoon

Session 5—Scientific Education

Dr. R. Ewell, Vice-Chancellor for Research, University of Buffalo.

Session 6—Molecular Electronics

H. V. Noble, Technical Director, Electronic Technology Lab., WADD.

Session 7—Space Reconnaissance Systems

A. Katz, Electronic Department, Rand Corp.

Session 8—Magnetohydrodynamics

Dr. A. Kantrowitz, Director, A VCO Research Lab.

Tuesday Morning, May 3

Session 9—Space Systems Integration

D. T. McRuer, Pres., Systems Technology, Inc.

Session 10—Bionics

J. E. Keto, Chief Scientist, WADD.

Session 11—Space Communications

Dr. W. B. LaBerge, Director of Systems Management, Philco Corp.

Session 12—Circuits

C. *Wiley, President, Wiley Electronics Co.*

Tuesday Afternoon

Session 13—Interplanetary Environment

Dr. C. D. Jones, College of Engineering, Ohio State University.

Session 14—Airborne Computers

Dr. W. Seman, Computation Lab., Harvard University.

Session 15—Guidance and Control Systems

Major L. C. Wright (USAF), Bureau of Research and Development, Federal Aviation Agency.

Session 16—Antennas and Propagation

Dr. D. D. King, Vice-President, Research, Electronic Communications, Inc.

Wednesday Morning, May 4

Session 17—Managing Space Systems

J. R. Moore, Vice-President—General Manager, Autonetics.

Session 18—Microwave Tubes

Dr. L. M. Field, Director, Physics Lab., Hughes Aircraft Co.

Session 19—Telemetry

J. A. Althouse, Technical Consultant, Flight Control Lab., WADD.

Session 20—Electric Propulsion

Dr. W. J. O'Donnell, Republic Aviation

1960 Western Joint Computer Conference

JACK TAR HOTEL, SAN FRANCISCO, CALIF, MAY 3–5, 1960

The executive committee for the 1960 Western Joint Computer Conference has announced appointments to head committees preparing for the three-day conference May 3–5 at the Jack Tar Hotel in San Francisco, Calif.

Robert M. Bennett, Jr., of the IBM Research Laboratory, San Jose, Calif., general chairman, has been joined by George A. Barnard of Ampex Corp., Redwood City, Calif., vice-chairman, and J. P. Fernandez of the IBM Product Development Laboratory, San Jose, Calif., secretary-treasurer, in announcing the chairmanships.

Chairman of the technical program is Howard M. Zeidler of Stanford Research Institute, Menlo Park, Calif. Program vice-chairman is Jack E. Sherman of Lockheed Missile and Space Division, Palo Alto, Calif.

Chairman of exhibits will be Harry K. Farrar of Pacific Telephone & Telegraph Co., San Francisco, Calif.

Heading local arrangements will be Gene E. Morrison of Smith-Corona Marchant, Inc., of Oakland, Calif.

Robert A. Isaacs and Roger Wye of Philco Corp., Palo Alto, Calif., are chairman and vice-chairman for printing and mailing.

Public relations will be headed by Charles Elkind of Stanford Research Institute. Normay J. Jones of Friden, Inc., San Leandro, Calif., is public relations vice-chairman.

D. D. Willard and Earl T. Lincoln of IBM Product Development Laboratory are chairman and vice-chairman of the publications committee.

Heading the registration committee is Harold N. Wells of General Electric Computer Laboratory, Palo Alto, Calif.

Women's activities will be arranged by a committee headed by Mary Fraser of IBM Research Laboratory.

Joint sponsors of the 1960 WJCC are the Institute of Radio Engineers, the American Institute of Electrical Engineers and the Association for Computing Machinery.

Session on Computer Organization Trends

Chairman: *A. J. Critchlow, IBM, Mohansic, N. Y.*

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"The Historical Development and Predicted State-of-the-Art of the General Purpose Digital Computer," *C. Bourne and D. Ford, Stanford Research Institute, Menlo Park, Calif.*

"The Harvest System," P. O. Herwitz and J. H. Pomerene, *IBM, Poughkeepsie, N. Y.*

"Organization of Computer Systems—The Fixed Plus Variable Structure Computer," *G. Estrin, University of California, Los Angeles, Calif.*

"Horizons in Computer Systems Design," *W. F. Bauer, Ramo-Wooldridge Corp., Los Angeles, Calif.*

Panelists: *G. Amdahl, Aeronutronics Corp., Santa Ana, Calif.; M. M. Astrahan, IBM, San Jose, Calif.; and J. W. Leas, RCA, Camden, N. J.*

Session on Data Retrieval

Chairman: *R. M. Hayes, Electrada Corp.*

"A Multi-Level File Structure for Information Processing," *L. Miller, J. Minker, W. G. Reed, and W. E. Shindle, RCA, Lancaster, Pa.*

"Symbolic Logic in Language Engineering," *H. M. Semarne, Douglas Aircraft Co., Inc., Santa Monica, Calif.*

"The Fact Compiler—A System for the Extraction, Storage, and Retrieval of Information," *C. Kellogg, Ramo-Wooldridge Corp., Los Angeles, Calif.*

Panelists: *to be announced.*

Session on Learning and Problem Solving Machines

Chairman: *T. A. Kalin, M.I.T., Cambridge, Mass.*

"Empircal Explorations of the Geometry Theorem Machine," *H. Gelernter, J. R. Hansen, and D. W. Loveland, IBM, Yorktown Heights, N. Y.*

"Recognition of Sloppy Hand-Printed Characters," *W. Doyle, M.I.T., Cambridge, Mass.*

"A Suggested Model for Information Representation in a Computer That Perceives, Learns, and Reasons," *P. H. Greene, University of Chicago, Chicago, Ill.*

Panelists: *O. Selfridge, M.I.T., Cambridge, Mass.; J. C. R. Licklider, Bolt, Beranek, and Newman, Inc., Boston, Mass.; and H. J. Bremermann, University of California, Berkeley.*

Session on Analog Equipment

Chairman: *R. M. Howe, University of Michigan, Ann Arbor.*

"Analog Time Delay System," *C. D. Hofmann and H. L. Pike, Convair Astronautics, Pomona, Calif.*

"DAFT: A Digital/Analog Function Table," *R. M. Beck and J. M. Mitchell, Packard Bell Computer Corp., Los Angeles, Calif.*

"Mathematical Applications of the Dynamic Storage Analog Computer," *J. M. Andrews, Computer Systems, Inc., New York, N. Y.*

Panelists: *to be announced.*

Session on Components and Techniques

Chairman: *R. Minnick, Stanford Research Institute, Menlo Park Calif.*

"Characteristics of a Multiple Magnetic Plane Thin Film Memory Device," *K. D. Broadbent, S. Shohara, and G. Wolfe, Jr., Hughes Aircraft Co., Los Angeles, Calif.*

"Unifluxor: A Permanent Memory Element," *A. M. Renard, Aeronutronics, Van Nuys, Calif.; and W. J. Neumann, Remington Rand Univac, St. Paul, Minn.*

"A Rapid Access Transistor Driven Non-Destructive Read-Out Memory," *D. G. Fischer and T. C. Penn, Texas Instruments, Inc., Dallas, Texas.*

Panelists: *D. A. Meier, National Cash Register, Hawthorne, Calif.; and N. L. Kreuder, Electrodata, Pasadena, Calif.*

Session on Analog Techniques

Chairman: *H. Skramstad, National Bureau of Standards, Washington, D. C.*

"On the Reduction of Error in Certain Analog Computer Calculations by the Use of Constraint Equations," *R. M. Turner, Lockheed Aircraft Corp., Burbank, Calif.*

"The Use of Parameter Influence Coefficients in Computer Analysis of Dynamic Systems," *H. F. Meissinger, Hughes Aircraft Co., Los Angeles, Calif.*

"Analog Computer Techniques for Plotting Bode and Nyquist Diagrams," *G. A. Bekey and L. W. Neustadt, Space Technology Labs., Inc., Los Angeles, Calif.*

Panelists: *to be announced.*

Session on Trends in Computer Applications

Chairman: *T. W. Wilder, Broadview Research Corp.*

"Trends in Computer Applications," *J. M. Salzer, Ramo-Wooldridge Corp., Canoga Park, Calif.*

"The Outlook for Machine Translation," *F. L. Alt, National Bureau of Standards.*

"Computers for Field Artillery," *L. R. van de Velde, Fort Sill, Okla.*

Panelists: *C. E. Miller, Electronic Computing Center, San Francisco, Calif.; A. R. Zipf, Bank of America, San Francisco, Calif.; and G. W. Evans, Stanford Research Institute, Menlo Park, Calif.*

Session on Logical Design

Chairman: *R. I. Tanaka, Lockheed Aircraft Corp., Burbank, Calif.*

"Communications Within a Polymorphic Intellectronic System," *G. P. West and R. T. Koerner, Ramo-Wooldridge Corp., Los Angeles, Calif.*

"Encoding of Incompletely Specified Boolean Matrices," *T. A. Dolotta and E. J. McCluskey, Jr., Princeton University, Princeton, N. J.*

"A Built-in Table Lookup Arithmetic Unit," *R. C. Jackson, W. H. Rhodes, Jr., W. D. Winger, and J. G. Brenza, IBM Corp., Poughkeepsie, N Y.*

Panelists: *A. Jennings, California Computer Products, Downey, Calif.; D. Aufenkamp, General Electric Co., and B. Elspas, Stanford Research Institute, Menlo Park Calif.*

Session on Design, Programming and Sociological Implications of Microelectronics

Chairman: *L. Fein, Consultant, Palo Alto, Calif.*

"On Microelectronic Components, Interconnections, and System Fabrication," *K. R. Shoulders, Stanford Research Institute, Menlo Park, Calif.*

"On Iterative Circuit Computers Constructed of Microelectronic Components and Systems," *J. H. Holland, University of Michigan, Ann Arbor.*

"On Programming a Highly Parallel Machine to be an Intelligent Technician," *A. Newell, The Rand Corp., Santa Monica, Calif.*

"On a Potential Customer for an Intelligent Technician," *C. W. Churchman, University of California, Berkeley.*

Session on Analog Applications

Chairman: *L. Wadel, Chance-Vought Aircraft Corp., Dallas, Tex.*

"ANATRAN—First Step in Breeding the DIGINALOG," *L. A. Ohlinger, Norair Division of Northrop Corp.*

"Using an Analog Computer for Both Systems Analysis and Operator Training on the Enrico Fermi Nuclear Power Plant," *R. Kley, Holley Carburetor Co.*

"Real-Time Automobile Ride Simulation," *R. H. Kohr, General Motors Corp.*

Panelists: *to be announced.*

Session on Programming Systems

Chairman: *G. H. Mealy, Rand Corp., Santa Monica, Calif.*

"A New Approach to the Programming Problem," *W. Orchard-Hays, Corporation for Economic and Industrial Research.*

"The Operator Oriented Language—A Computer Language," *G. F. Ryckman, General Motors Corp.*

"A Man-to-Machine Communication and Automatic Code Translation," *A. W. Holt and W. J. Turanski, Moore School of Electrical Engineering, University of Pennsylvania, Philadelphia (on leave from Remington Rand Univac).*

Panelists: *to be announced.*

Session on Input-Output and Communications

Chairman: *J. A. McLaughlin, IBM, San Jose, Calif.*

"A Line-Drawing Pattern Recognizer," *L. D. Harmon, Bell Telephone Labs., Murray Hill, N. J.*

"Automatic Store and Forward Message Switching System," *J. L. Owings, T. L. Genetta, and J. F. Page, RCA, Camden, N. J.*

"The Videograph Label Printing System Developed for Time, Inc.," *B. H. Klyce, Time, Inc., New York, N. Y., and J. J. Stone, A. B. Dick Co.*

Panelists: *J. Svigals, IBM, Los Angeles, Calif.; and G. Warfel, Bank of America, San Francisco, Calif.*

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THE FIRST — An ultra-fast computer diode: Four millimicrosecond maximum reverse recovery time of this new FD 100 overcomes the diode-caused speed limitations in computer circuits. Capacitance is only 2$\mu\mu$f at zero volts bias.

THE REASON — A need and the technology to serve it: Fairchild's diffused silicon transistors have achieved heretofore unattainable performance. Application of these transistors has in turn created the need for silicon diodes of similarly outstanding performance.

THE FOLLOW UP — A broad line of high reliability diodes: This Fairchild FD 100 diode is being followed by others providing industry-leading standards in reliability and uniformity — backed by a continuing accumulation of statistical data on a large scale.

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25°C Except As Noted

Symbol	Characteristic	Min.	Max.	Conditions
BV	Breakdown Voltage	40 volts		@ $I_R = 100\ \mu A$
I_R	Reverse Current		.100 μA	@ $V_R = 30v$, 25°C
V_F	Forward Voltage Drop		1 v	@ $I_F = 10$ mA
C	Capacitance		2 $\mu\mu$f	@ $V_R = 0v$
t_{rr}	Reverse Recovery Time To Ir = 1 ma		4 mμs	@ $I_f = I_r = 10$ ma
	Maximum Power Dissipation		200 mw.	
	Temp. Range Operating	-65°C to 175°C		
	Storage	-65°C to 200°C		

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PGMTT National Symposium

HOTEL DEL CORONADO, SAN DIEGO, CALIF., MAY 9–11, 1960

Welcome and Opening Remarks
Monday Morning, May 9

D. Proctor, Chairman of the 1960 PGMTT National Symposium.

A. A. Oliner, National Chairman of the PGMTT.

Session 1—Microwave Components and Systems

Chairman: *T. N. Anderson, FXR Inc., Long Island City, N.J.*

"New Developments in Microwave Communications Systems," *C. C. Cutler, Bell Telephone Labs., Holmdel, N. J.*

"Mode Conversion in Helix Waveguide," *H.G. Unger, Bell Telephone Labs., Holmdel, N. J.*

"Some Properties of Dielectric Loaded Slow Wave Structures," *G. B. Walker and C. G. Engelfield, Univ. of British Columbia, Vancouver, B. C., Canada.*

"UHF Strip Transmission Line Hybrid Junction," *I. Tatsughuchi, Bell Telephone Labs., Whippany, N. J.*

"A Variable Slope, Non-Dispersive Microwave Phase Shifter," *G. D. Carey and R. E. Hovda, Autonetics, Div. of North American Aviation, Downey, Calif.*

"A Wide-Band Turnstile Junction and Direction Finding Antenna," *R. C. Honey and J. K. Shimizu, Stanford Res. Inst., Menlo Park, Calif.*

"Microwave Phase Analyser," *K. D. Claborn and R. E. Jones, Bendix Radio, Div. of Bendix Aviation Corp., Baltimore, Md.*

Monday Afternoon

Session 2—Parametric Amplifiers

Chairman: *A. Berk, Research Labs., Hughes Aircraft Co., Culver City, Calif.*

"Gallium Arsenic Point Contact Diodes," *W. M. Sharpless, Bell Telephone Labs., Holmdel, N. J.*

"Characterization of Microwave Variable Capacitance Diodes," *S. T. Eng., Development Lab., Hughes Semiconductor Div., Newport Beach, Calif.*

"A Perturbation Theory for Parametric Amplifiers," *R. H. Kingston and A. L. McWhorter, Lincoln Lab., M.I.T., Lexington, Mass.*

"A Study of the Optimum Design of Wideband Parametric Amplifiers and Up-Converters," *G. L. Matthaei, Stanford Res. Inst., Menlo Park, Calif.*

"A Low-Noise X-Band Parametric Amplifier," *R. D. Weglein, Research Labs., Hughes Aircraft Co., Culver City, Calif., and F. Keywell, Semiconductor Div., Hughes Products, Costa Mesa, Calif.*

"A Four Terminal Low Noise Parametric Microwave Amplifier," *W. Eckhardt and F. Sterzer, RCA, Princeton, N. J.*

"Design and Operation of Four-Frequency Parametric Up-Converters," *J. A. Luksch, E. W. Matthews and G. A. VerWys, RCA, Moorestown, N. J.*

"A Study of the Iterated Traveling-Wave Parametric Amplifier," *C. V. Bell, Walla Walla College, College, Park, Wash.*

Monday Evening

Session 2A—Parametric Amplifiers

Panel Discussion: *A. Berk, Research Labs., Hughes Aircraft Co., Culver City, Calif.; C. J. Carter, Space Technology Labs., Los Angeles, Calif.; J. C. Green, Airborne Instruments Lab., Melville, L.I., N. Y.; E. M. T. Jones, Stanford Res. Inst., Menlo Park, Calif.;* N. *Uenohara, Bell Telephone Labs., Murray Hill, N. J., G. Wade, Stanford Univ., Stanford, Calif.*

Tuesday Morning, May 10
Session 3—Ferrites

Chairman: *N. Sakiotis, Motorola, Inc., Scottsdale, Ariz.*

"Non-Linear Effects in Ferrites," *M. Weiss, Research Labs., Hughes Aircraft Co., Culver City, Calif.*

"Ferroxplane Type Materials at Microwave Frequencies," *I. Bady, U. S. Army Signal Res. and Dev. Lab., Fort Monmouth, N. J.*

"Antiferromagnetic Materials for Millimeter and Sub-millimeter Devices," *G. S. Heller and J J. Stickler, Lincoln Lab., M.I.T., Lexington, Mass.*

"Design Problems Associated with Rectangular Waveguide Reciprocal Phase-shifters," *A. Clavin, RANTEC Corp, Calabasas, Calif.*

"Magnetstatic Modes and Ferrites with Conventional Waveguide Geometries," *G. P. Rodrigue, Sperry Microwave Electronics Co., Clearwater, Fla.*

"Wide Band Resonance Isolator," *W. W. Anderson and M. E. Hines, Bell Telephone Labs., Murray Hill, N. J.*

"An Electrically-Variable, Reciprocal Ferrite Phase Shifter," *R. W. Kordos and V. J. McHenry, Research Labs. Div., Bendix Aviation Corp., Detroit, Mich.*

Tuesday Afternoon

Session 4—Millimeter Waves and Diode Applications

Chairman: *P. Vartanian, Melabs, Palo Alto, Calif.*

"Millimeter Wave Generation," *B. Epsztein, Microwave Res. Inst., Brooklyn, N. Y. (on leave from Compagnie General TSF, France)*

"Millimeter Wave Generation by Parametric Methods," *G. H. Heilmeier, RCA Labs., David Sarnoff Res. Center, Princeton, N. J.*

"A Pulsed Ferrimagnetic Microwave Generator," *B. J. Elliott, T. Schaug-Petersen and H. J. Shaw, Stanford Univ., Stanford, Calif.*

"Maser Operation at Signal Frequencies Higher Than the Pump Frequency," *F. R. Ames, Airborne Instruments Lab., Melville, L. I., N. Y.*

"Generation of Microwaves by Means of Esaki Diodes," *R. F. Rutz, Research Labs., IBM, Poughkeepsie, N. Y.*

"The Large Signal Behavior of a Cavity Type Parametric Amplifier," *F. A. Olson and G. Wade, Stanford Univ., Stanford, Calif.*

"A Solid State Microwave Source from Reactance Diode Harmonic Generators," *T. M. Hyltin and K. L. Kotzebue, Texas Instruments, Dallas, Tex.*

Wednesday Morning, May 11

Session 5—Microwave Propagation in Plasmas and Solids

Chairman: *L. Goldstein, Univ. of Illinois, Urbana.*

"Propagation of Waves in a Plasma in a Magnetic Field," *W. Allis, Research Lab. of Electronics, M.I.T., Cambridge, Mass.*

"Plasma-Electromagnetic Interaction," *N. Marcuvitz, Microwave Res. Inst., Polytechnic Institute of Brooklyn, Brooklyn, N. Y.*

"Magnetoplasma Effects in Semiconductors," *B. Lax, Lincoln Labs., M.I.T., Lexington, Mass.*

"Coherent Excitation of Plasma Oscillations in Solids," *D. Pines, Univ. of Illinois, Urbana (work done at General Dynamics Corp., San Diego, Calif.)*

Panel Discussion: *O. T. Fundingsland, Raytheon Mfg. Co., Waltham, Mass.; R. Gould, California Institute of Technology, Pasadena; H. Margenau, Yale Univ., New Haven, Conn.; R. F. Whitmer, Sylvania Electronic System, Mountain View, Calif.*

Wednesday Afternoon

Session 6—Filters and Measurements

Chairman: *K. Tomiyasu, General Electric Microwave Lab., Palo Alto, Calif.*

"Lossy Waveguide Resonators," *H. Riblet, Microwave Development Labs., Inc., Wellesley, Mass.*

"Peak Internal Fields in Direct Coupled Cavity Filters," *L. Young, Westinghouse Electric Corp., Baltimore, Md.*

"Strip Transmission Line Directional Filter," *R. L. Sleven and P.E. Dorato, Airborne Instruments Lab., L. I., N. Y.*

"Application of the Smith Chart to Problems of Propagation in a Magneto-Ionic Medium," *G. A. Deschamps and W. L. Weeks, Univ. of Illinois, Urbana.*

"Microwave Measurements of Electron Attachment Rates," *V. A. J. van Lint and E. G. Wilkner, General Atomic, Div. of General Dynamics Corp., San Diego, Calif.*

"Fractional Millimicrosecond Electrical Stroboscope," *W. M. Goodall and A. F. Dietrich, Bell Telephone Labs., Holmdel, N. J.*

The banquet speaker at the PGMTT National Symposium will be W. E. Edson of the General Electric Co., Palo Alto, Calif., who will speak on "Microwave Power Sources of the Future."

Oui, General Transistor offre des transistors MIL/SPEC

GERMANIUM PNP

2N43A	MIL T 19500/18
2N44A	MIL T 19500/6
2N331	MIL T 19500/4A
2N404	MIL T 19500/20
2N416	MIL T 19500/56
2N417	MIL T 19500/57
2N425	MIL T 19500/45
2N426	MIL T 19500/42
2N427	MIL T 19500/43
2N428	MIL T 19500/44
2N464	MIL T 19500/49
2N465	MIL T 19500/50
2N466	MIL T 19500/51
2N467	MIL T 19500/45

GERMANIUM NPN

2N358A	MIL T 19500/63
2N388	MIL T 19500/65
2N1310	Guidance

SILICON PNP

2N327A	
2N328A	Guidance
2N329A	Guidance
2N1026	Guidance

DIODES

General Transistor also produces high-reliability gold-bonded diodes, three of which are designed to meet MIL requirements: 1N198, 1N277, and 1N281. The spec numbers are, respectively: MIL E 1/700, 1/993A, and 1/961.

The semiconductors listed on this page are all designed to meet MIL specs.

GENERAL TRANSISTOR CORP.

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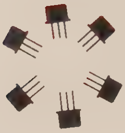
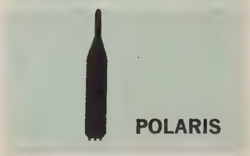
These NPN Germanium Types



As witness the deployment of General Transistors on projects such as:

BMEWS

MINUTEMAN



POLARIS

HAWK

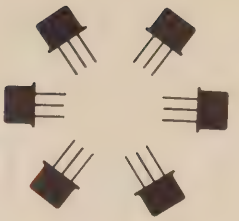
And many other military programs. Why? *Reliability.*

General Transistor is now in its fourth year of production on *quality* NPN germanium transistors. We were one of the earliest suppliers of germanium NPN transistors, and have from the beginning maintained an excellent reputation for highly reliable products. Listed are some characteristically fine types.

Type No.	Collector-Base Breakdown V_{CBO} (Volts)	Punch thru V_{pt} (Volts)	Collector Cutoff Current I_{CO} (μa)	D.C. Current Gain h_{FE}	Alpha Cutoff Frequency f_{ab} (mc)
2N356A	40	40	3	35	3
2N357A	40	40	3	40	6
2N439	40	35	3	60	8
2N440	40	30	3	100	12
2N446A	30	35	2	100	8
2N447A	30	25	2	150	12
2N595	35	30	2	50	5
2N596	35	30	2	70	8
2N1012	50	50	2	60	5

Typical values

Also on Military Duty



...and here's a flight of high voltage types:

		2N1310			2N1311			2N1312		
DISSIPATION RATINGS:		NPN			NPN			NPN		
		GE Alloy Junction			GE Alloy Junction			GE Alloy Junction		
TOTAL TRANSISTOR DISSIPATION AT 25°C		120 MW			120 MW			120 MW		
DERATING FACTOR		2 MW/°C			2 MW/°C			2 MW/°C		
STORAGE TEMPERATURE		—65°C to 85°C			—65°C to 85°C			—65°C to 85°C		
CUT-OFF RATINGS:	CONDITIONS	MIN	TYP	MAX	MIN	TYP	MAX	MIN	TYP	MAX
COLLECTOR BASE VOLTAGE (V_{CBO})	I_C=25 µa	90 v			75 v			50 v		
EMITTER-BASE VOLTAGE (V_{EBO})	I_E=25 µa	20 v	50 v		20 v	50 v		20 v	40 v	
COLLECTOR-EMITTER VOLTAGE (V_{PT}) (PUNCH-THRU)	I_E=25 µa	90 v			75 v			50 v		
COLLECTOR CUT-OFF CURRENT (I_{CO})	V_{CBO}=5 v		3 µa	7 µa		3 µa	7 µa			7 µa
EMITTER CUT-OFF CURRENT (I_{EO})	V_{EBO}=5 v		3 µa	7 µa		3 µa	7 µa			7 µa
D.C. AND SWITCHING RATINGS:										
D.C. CURRENT GAIN (h_{FE})	I_C=5 ma V_{CE}=0.25 v	20			15					
	I_C=20 ma V_{CE}=0.25 v					25		20	30	
D.C. BASE VOLTAGE (V_{BE})	I_C=5 ma V_{CE}=0.25 v			0.5 v			0.5 v			
	I_C=20 ma V_{CE}=0.25 v								0.3 v	
D.C. COLLECTOR VOLTAGE (V_{CE})	I_B=10 ma I_C=100 ma		0.2 v			0.2 v			0.2 v	
SMALL SIGNAL RATINGS:										
CURRENT GAIN COMMON EMITTER (h_{fe})	V_{CE}=5 v I_E=1 ma f=1 kc		35			30			40	
ALPHA CUT-OFF FREQUENCY (f_{ab})	V_{CB}=5 v I_E=1 ma		1 mc			1.5 mc			2 mc	
COLLECTOR CAPACITY (C_{ob})	I_E=1 ma V_{CB}=5 v f=1 mc		11 µµf			11 µµf			11 µµf	
INPUT IMPEDANCE (h_{ib})	V_{CB}=5 v I_E=1 ma f=1 kc		35 Ω			35 Ω			35 Ω	
REVERSE TRANSFER RATIO (h_{rb}) (X 10^{-4})	V_{CB}=5 v I_E=1 ma f=1 kc			15			15			15
OUTPUT ADMITTANCE (h_{ob})	V_{CB}=5 v I_E=1 ma f=1 kc			2 µ℧			2 µ℧			2 µ℧
NOISE FIGURE (NF)	V_{CB}=5 v f=1 kc I_E=1 ma BW=100~		10 db			10 db			10 db	

Because of the relative newness of these transistors, data is presented in detail.

GENERAL TRANSISTOR CORP.

Speaking of Services: GT Hi/Scope Service

100% Lot Preconditioning

Let's assume you have equipment which must undergo severe environmental conditions...be subjected to high mechanical shock and vibration. To be certain that all the transistors you intend to use will withstand this type of exposure, we will set up a preconditioning program that will test out every single unit before we ship to you.

Special Electrical Parameter Testing

Certain transistor applications are so unusual that they cannot be completely described by standard parameters. If you are in such a position, we will design a test fixture to closely approximate actual circuit performance. This procedure will provide assurance that 100% of the transistors delivered to you will perform satisfactorily.

Special Reliability Testing Programs

Must your completed systems meet a high reliability requirement? If so, you may wish special procedures to be established with regard to your reliability programs. This is another GT service. When necessary, we will build such transistors on a specially designed production line, check them exhaustively to hold tight parameter tolerances, and subject large lots to specific and unique life tests. In many cases, we have established a program so that we ship those units which have high survival probability in your application. These things we have done, and will do again, at your request. Sound helpful?

High and Low Temperature Testing

Standard transistor parameters are generally controlled at room temperature. Yet many systems must function at other ambients. If you have a problem specifying electrical parameters at room temperature in a manner that will be valid at high or low temperatures, we are ready to assist. General Transistor is prepared to run any measurements you dictate, at any specified ambient. We can do this on complete production lots if you feel it essential.

Cost Economies Through Parameter Modifications

Yield has a strong influence on transistor cost. To give you the best economies and at the same time give you the most desirable quality, we offer this working arrangement. At your request, General Transistor will suggest slight modifications of your specifications which will allow us to ship the major portion of a production run. We will make the necessary measurements and indicate what the various parameters should be and what proportions of the run will fall into preselected types. If you then design your system to use this production mix, you will benefit from some genuine economies.

Circuit Design

If you are starting on a new program, you may want some information on what performance you can expect from state-of-the-art circuits. We will provide you with such typical circuits at your request, together with data on the performance of our transistor types within these circuits.

Special Selection on Standard Catalog Types

In many instances you may find that a standard catalog transistor is about 90% acceptable, but still needs improvement in a few parameters. In such a case, please ask us about the possibility of getting these improvements. We can tell you what increase in specifications is feasible, and produce the units to this spec. Thus, you get the desired parameters without having to redesign or wait for a custom-built semiconductor.

Qualification Approvals

Let's consider the case where you want to design a certain transistor into a system for the government, yet a government specification does not exist for the transistor. You must be ready to substantiate your use of the nonstandard part. Here's what GT can do to help your case. We will run a qualification approval procedure in the same format we would for a military type. Then we'll provide you with this necessary data. This will greatly accelerate your approval for use of this transistor type.

Special Coatings or Encapsulations

In your manufacturing process, do you expose transistors to any kinds of solvents or potting materials? If so, just let us know. By using special highly resistant coatings, we'll make sure that the transistor case and markings are not vulnerable to solvent attacks.

Samples with Parameter Measurements

Assume you want to check out the margins in a design. You require upper and lower limit samples of a certain transistor type. We'll be happy to supply you with sufficient samples to cover the spread in one or two significant parameters. Thus, you can experimentally determine the performance of your circuit.

Special Production Runs

Assume that your transistor application is so unusual that units are not available from standard production. What can be done? We will analyze your requirements and decide whether it would be feasible to make a special production run of transistors to meet your needs.

What More?

This is our HI/SCOPE service...or a large part of it. Our customers have found it to be extremely useful. We think you will, too. If there is something still further that interests you, why not get in touch with us? Space precludes our going into too great detail here, but we feel sure you'll find any assistance you need at GT. Write or give us a phone call.

GENERAL TRANSISTOR CORP.

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1960 Electronic Components Conference

WASHINGTON HOTEL, WASHINGTON, D. C., MAY 10–12, 1960

Tuesday Morning, May 10

"Welcome," *R. L. Henry, Jr., General Chairman.*

Session 1—Quo Vadis, 1970

Moderator: *J. A. Chambers, Motorola.*

"Systems Requirements for Components in the Next Decade," *F. Lack, EIA.*

"The Components of 1970," *H. Stone, Bell Telephone Labs.*

"Research for Components of the Next Decade," *R. Adm. R. Bennett, Chief of Naval Research.*

Tuesday Afternoon

Session 2—Miniature and Packaged Components

Moderator: *Dr. R. M. Soria, Amphenol Electronics Co.*

"Recent Advances in Microminiaturization, Reliable Components and Cooling Techniques," *G. W. A. Dummer, Royal Radar Establishment, Great Britain.*

"Ceramic Base Microcircuits—A Heterogeneous Approach to Miniaturization," *M. H. Kahn, Sprague.*

"High Quality Ultra-Thin Film Capacitors," *S. Grand, Radiation Research Corp.*

"Rejection Filters with Distributed R&C," *A. Smith, Sprague.*

"2D Etched, Formed RC Circuits," *J. J. Kinsella and F. A. Schwertz, Haloid Xerox Inc.*

Tuesday Evening

Session 3—Special Commemorative Session—Signal Corps 100th Anniversary Presentation

Moderator: *V. Kublin, USASRDL.*

Wednesday Morning, May 11

Session 4—Microelectronic Components and Molecular Circuitry

Moderator: *C. W. Curtis, Hughes Aircraft Co.*

"The Philosophy of Molecular Electronics," *Dr. S. W. Herwald, Westinghouse.*

"Materials for Molecular Electronics," *Dr. Zener, Westinghouse.*

"Systems Aspects of Molecular Electronics," *Dr. Sziklai, Westinghouse.*

"Microelectronics and the Systems Design Engineer," *J. R. Black, Motorola.*

"Preparation and Evaluation of Thin Film Microcircuits," *J. J. Bohrer and G. N. Queen, IRC.*

"The Sylvania Microminiature Module," *G. J. Selvin, Sylvania.*

"Status Report on the Micromodule Program," *D. Mackey, J. Wentworth, RCA.*

Special Awards Luncheon

Speaker: *Maj. Gen. E. Cook, Deputy Chief Signal Officer.*

Wednesday Afternoon

Session 5—Advances in Components and Materials

Moderator: *F. Wenger, USAF-ARDC.*

"Gallium Phosphide Point Contact High Frequency Diodes," *J. Mandelkorn, USASRDL.*

"4-Layer PNPN Alloy Device," *R. Fidler, B. Carlat and R. Wegner, Tung-Sol Electric.*

"Means of Adjusting Resistive Micro Elements to the Desired Resistance Value," *R. C. Langford, Weston Instruments.*

"A Germanium Tunnel Diode," *T. R. Selig, GE, Syracuse.*

"Physics of Thin Resistive Films," *R. Conklin, Wright-Patterson AFB, E. R. Olson, Halex, Inc.*

"Ferromagnetic and Ferroelectric Ceramics; Matching Characteristics to System Needs," *Dr. H. W. Welch, Jr., Motorola.*

"Investigation of Columbium, as an Electrolytic Capacitor Anode," *C. Peabody and A. Lunchick, USASRDL.*

"Ruggedized Traveling Wave Tubes for Missile Use," *C. E. Bradford and J. P. Laico, Bell Telephone Labs.*

Thursday Morning, May 12

Session 6—Magnetic Components for Memory, Logic and Amplification

Moderator: *K. Preston, Bell Telephone Labs.*

"New Magnetic Devices for Digital Computers," *D. H. Looney, Bell Telephone Labs.*

"The Ferrite Sheet Memory," *R. H. Meinkan, Bell Telephone Labs.*

"Lesser Known Properties of Ferrite Multiapertured Cores," *U. F. Gianela, Bell Telephone Labs.*

"Reproducibility of Electrodeposited Thin Film Memory Arrays," *I. W. Wolf, GE, Syracuse.*

"Magnetic Rod Memory," *D. A. Meier, National Cash Register.*

"Counter-Wrapped Twistor," *R. F. Fische and P. Mallery, Bell, Telephone Labs.*

"The Amplifying Properties of Evaporated Magnetic Films," *D. W. Moore, Servomechanisms, Inc.*

Thursday Afternoon

Session 7—Achievements in Component Reliability

Moderator: *L. Podolsky.*

"DOD Presentation on Components Reliability Programs," *P. S. Darnell, leading a Panel Discussion.*

"Reliability Analysis of an Electronic Switching Center," *W. P. Karas, Stromberg-Carlson.*

"Electronic Parts and Reliability Assurance," *W. H. von Alven, ARINC Research Corp.*

"Reliability Analysis of Resistor Drift Characteristics," *B. R. Schwartz, RCA.*

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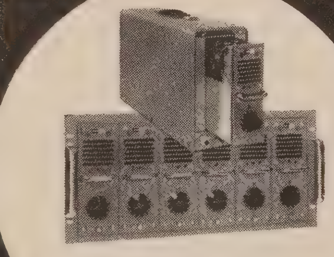

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Industrial Engineering Notes*

Association Activities

Dr. Lawrence W. Von Tersch, head of the Electrical Engineering Department at Michigan State University, has been elected President of the National Electronics Conference scheduled for October 10–12 at the Hotel Sherman in Chicago. Other officers named for the 16th annual NEC, in which EIA will participate, were: Executive Vice President, Joseph J. Gershon of DeVry Technical Institute; Secretary, James H. Kogen of GPE Controls, Inc., Treasurer, Dr. Harold E. Ellithorn of University of Notre Dame; Assistant Treasurer, Robert J. Parent of University of Wisconsin. Elected as NEC Chairman of the Board was William O. Swinyard, Vice President of Hazeltine Research, Inc. Committee chairmen elected were: Arrangements, Benjamin G. Griffith, Teletype Corporation; Exhibits, John S. Powers, Bell and Howell Company; Fellowship Award, Orville I. Thompson, DeVry Technical Institute; Finance Policy, Dr. John D. Ryder, Michigan State University; Housing, Juergen Roedel, Hallicrafters Company and International Activities, George E. Anner, University of Illinois.

FCC Actions

The FCC has declined to establish a TASO-type organization to complete the technical studies of the National Stereophonic Radio Committee as requested by EIA on October 15. In a letter to President Hull the FCC stated it wished to proceed expeditiously with FM stereo and that it proposed to issue a Notice of Proposed Rule Making shortly after March 15. President Hull had requested the commission to establish a Government-supervised committee similar to the Television Allocations Study Organization in response to a request from NSRC and on authorization of the EIA Board of Directors. NSRC has been unable to complete its studies, he told the FCC, because of the non-participation of RCA and CBS on legal grounds. He expressed the belief that these companies would participate if a TASO-type group were formed. Just what effect the Commission's refusal will have on the future work of NSRC was not immediately clear but will be determined within the next week or so. The NSRC was formed early in 1959 and carried on extensive technical studies under Chairman C. G. Loyd and Dr. W. R. G. Baker as Chairman of the Administrative Committee. . . . **The FCC has asked that $2,250,000 of its $13,500,000 budget request for 1961 be earmarked for the most thorough review of UHF yet.** Although plans have not been firmed up for the 2-year study, an FCC spokesman said last week the investigation would go considerably beyond previous ones on the feasibility of moving all or part of TV from VHF to UHF. Both transmitting and receiving operations would be covered. Much of the work would probably be contracted to private engineering firms, EIA learned. The commission also asked for $796,645 for research and work on frequency allocation matters. The total request increased by $2,950,000 over the 1960 appropriation.

Military Electronics

The Navy has made its first public demonstration of a new communications system which uses the moon as a passive reflector or relay of radio signals. The Moon Relay included teletypewriter communications between Washington and Hawaii, via the moon, and facsimile transmissions using the same method. Admiral Arleigh A. Burke, Chief of Naval Operations said: "The new Moon Relay communications system is the result of many years of Navy development utilizing the the moon—the least expensive satellite known to man." The pilot circuit, linking Washington and Hawaii, is an outgrowth of the Navy's communication project Moon Relay, established in 1956 to develop an experimental communications system for evaluation of the moon relay technique under operational conditions. Capabilities of this experimental system presently include multi-channel teletypewriter and facsimile modes of operation. Experimental work is also being done in voice communications, but at lower priority.

Space Launchings

A precise calendar of upcoming space shots was presented by Dr. Abe Silverstein, NASA's Director of Space Flight Programs. These major scientific, communications, and meteorological launchings through FY 1963 total just under 30 and include JUNO II, THOR-ABLE, SCOUT, DELTA, THOR-AGENA B, and ATLAS-AGENA B vehicles. Launchings leading up to interplanetary probes in 1963 in the vicinity of Venus and Mars, using the CENTAUR vehicle, will begin this year with three interplanetary shots using the THOR-ABLE. Next year, nine lunar launchings will be made using the DELTA, ATLAS-ABLE, and ATLAS-AGENA B, and four lunar shots will be made in 1962 employing the ATLAS-AGENA. The first launch of a payload specifically designed for the acquisition of meteorological data, known as TIROS, will be fired this summer, Dr. Silverstein detailed. This will be followed sometime in late 1961 or 1962 by

(Continued on page 40A)

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* The data on which these Notes are based were selected by permission from *Weekly Reports*, issues of January 25 and February 1 published by the Electronic Industries Association whose helpfulness is gratefully acknowledged.

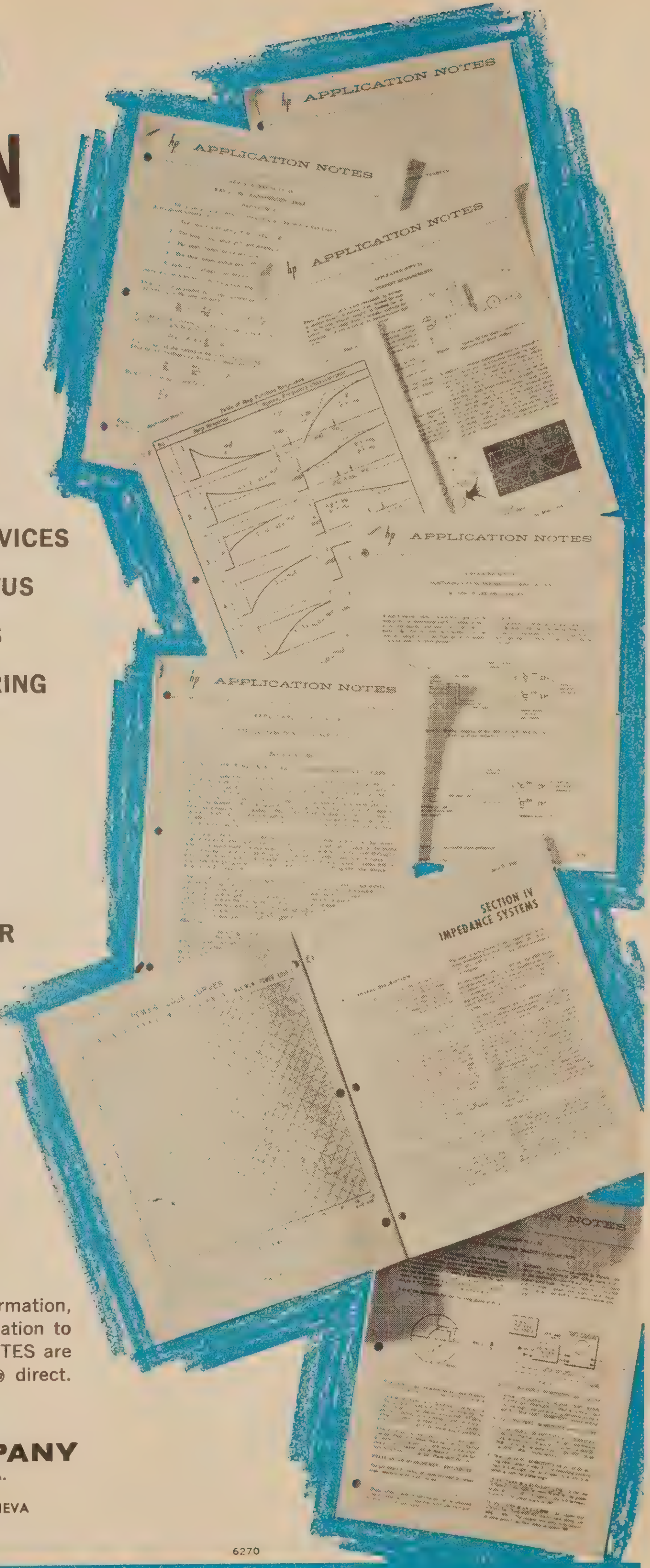
Which of these hp

APPLICATION NOTES

can help you?

- **#16** WAVES ON TRANSMISSION LINES
- **#17** SQUARE WAVE AND PULSE TESTING
- **#18** INTRODUCTION TO SOLID STATE DEVICES
- **#21** MICROWAVE STANDARDS PROSPECTUS
- **#27** BASIC MICROWAVE MEASUREMENTS
- **#29** CONVENIENT METHOD FOR MEASURING PHASE SHIFT
- **#30** MEASUREMENT OF CABLE CHARACTERISTICS
- **#34** AC CURRENT MEASUREMENTS
- **#36** SAMPLING OSCILLOGRAPHY
- **#37** MONITORING A RADIO TRANSMITTER SIGNAL WITH AN hp 120A OR 130B OSCILLOSCOPE
- **#38** MICROWAVE MEASUREMENTS FOR CALIBRATION LABORATORIES
- **#39** STANDARDS CALIBRATION PROCEDURES
- **#40** HEWLETT-PACKARD ELECTRONICS INSTRUMENTATION FOR TRANSDUCER APPLICATIONS

The above involve both theoretical and "how to do it" information, illustrated, complete, designed for swift practical application to your problem. These and all other hp APPLICATION NOTES are available by calling your hp representative, or writing hp direct. No charge, no obligation.



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Barriers across both faces increase creepage path; elongated holes facilitate mounting; nesting projection and recess aid stacking. Brass receptacles provide low contact resistance. 14 lbs. min. pull out with standard solderless taper pins. Molding compound is MAI-60 (Glass Alkyd) of MIL-M-14E.

Gen-Pro boards have passed Navy 2,000 ft. lb. high shock requirements as specified by MIL-S-901B.

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Industrial Engineering Notes

(Continued from page 38A)

a second version of the same payload, with additional sensing equipment, known as NIMBUS. This later satellite will contain more instrumentation than TIROS and will be stabilized so that the sensors will point at the earth throughout the flight path, he said. Passive communication experiments known as PROJECT ECHO—reflecting radio signals from one ground transmitting station to another—will "receive considerable attention in the months ahead," Dr Silverstein said. But he cautioned that neither meteorological nor communications experiments "in the next several years should be considered as an early approach to an operational system." Rather, he said, these "are experiments aimed at furthering the science and technology in these areas. Operational systems will come later and only after the problems have been identified and solved." In presenting a broad picture of the national space exploration program, NASA's Deputy Administrator Hugh L. Dryden said the development of meteorological satellites is one of its most important goals. "Still in the earliest R&D stage as regards the instrumentation," he noted, "the results already obtained open new vistas to the forecaster and research scientist alike." Dr. Dryden supported the testimony of Mr. Horner.

Professional Group Meetings

AERONAUTICAL AND NAVIGATIONAL ELECTRONICS

Akron—December 8

"Methods of Continuous Radar Performance Monitoring," L. H. Fisher, Polytechnic Res. & Dev. Co.

Boston—January 13

"Digital Computers for Doppler Data," E. Ostroff, Lab. for Electronics, Inc.

Oklahoma City—December 22

"The FAA Air Surveillance Radar ASR-4," F. W. Simonds, Texas Instruments.

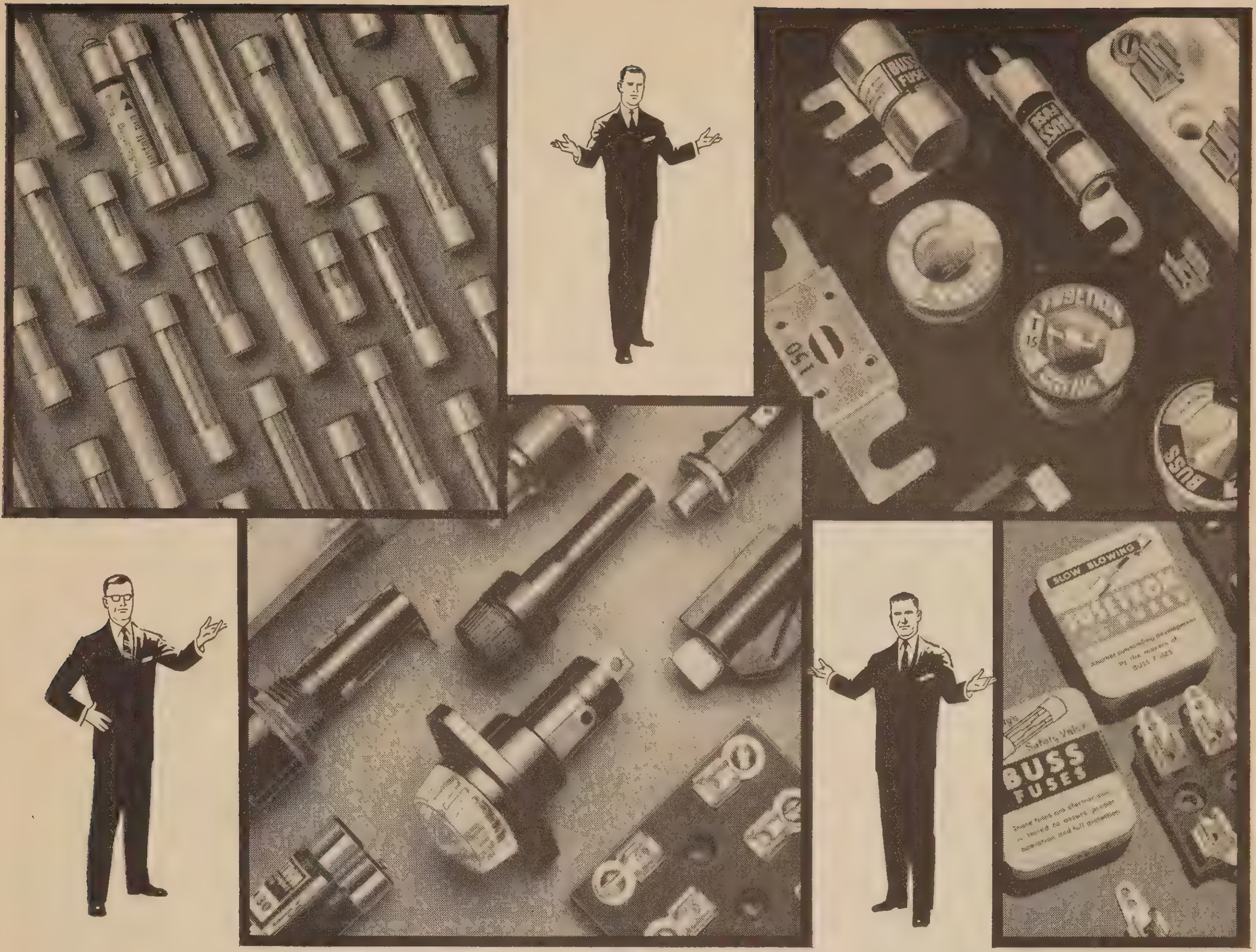
ANTENNAS AND PROPAGATION

Boston—January 13

"A Circular-Linear Polarized Shaped-Beam Airport Surveillance Radar Antenna," A. J. Simmons and C. A. Lindberg, TRG, Inc.

"Measurements of Lunar Reflectivity Using The Millstone Radar," G. H. Pettengill, M. I. T. Lincoln Lab.

(Continued on page 44A)



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IT'S A FACT! By specifying BUSS fuses, you obtain the finest electrical protection possible — and you help safeguard the reputation of your product for quality and reliability.

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IT'S A FACT! Whatever your fuse requirements, there's a dependable BUSS or FUSETRON fuse to satisfy them. Sizes from 1/500 ampere up and there's a companion line of fuse clips, blocks and fuseholders.

IT'S A FACT! The BUSS fuse engineering staff will work with you to help you find or develop the best-suited to your needs. This places the world's largest fuse research laboratory and its personnel at your command to save you engineering time.

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BUSS fuses are made to protect - not to blow, needlessly.
BUSS makes a complete line of fuses for home, farm, commercial, electronic, electrical, automotive and industrial use.

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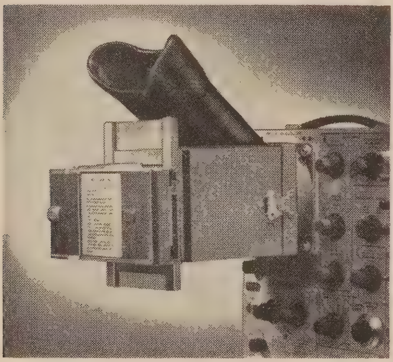
NEWS New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

Oscilloscope Camera

A completely new oscilloscope recording camera is introduced by **Beattie-Coleman, Inc.,** 1082 N. Olive St., Anaheim, Calif. Known as the "Minute Man Oscillotron," it features a Polaroid® Land back providing either 60 second prints or transparencies. Attaches to any 5″ Oscilloscope. Swings out, lifts off for accessibility. Light and compact, it is a precision instrument built for continuous duty. Wollensak 75mm f/2, 8, f/1.9 standard or f/1.9 flat-field lenses are interchangeable.



Of modular design, it can instantly be converted to record a wide range of object-to-image ratios. Can be removed from oscilloscope for other instrumentation photography.

Easily attached accessories include: Binocular viewing hood; adapter to record up to 10 traces on a single frame: 35 mm pulse camera; 35 mm continuous motion magazine; data chamber with watch, platen, and counter; data card to record in frame; external focusing control; electric shutter actuator.

Price of the basic unit is $250.00.

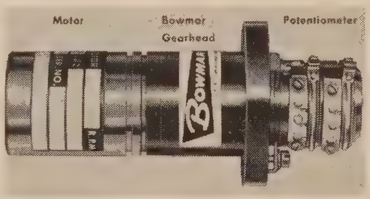
Digital Switch Assembly

A new modular digital switch assembly containing 1 to 16 thin thumbwheel switches in either 8, 10 or 12 positions with numerical readout has been designed by **Chicago Dynamic Industries, Inc., Precision Products Div.,** 1725 Diversey Blvd., Chicago 14, Ill. Series TSD may be positioned horizontally or vertically with engraved numbers or designations to suit. The unit is available with either instantly replaceable printed circuit wafers for quick servicing and low maintenance costs, or with fixed wafers if removable feature is not required. Switches are manually operated by $\frac{1}{4}$″ Delrin thumbwheels available in black or colors for each module.

Immediate delivery on standard units. Prices range from $2.27 to $5.58 per module depending upon quantity and type of switch.

Miniature Female Gearhead

A new miniature female size 11 gearhead, Model X-1135, that affords easy integration of motor and potentiometers through the desired speed reduction has been developed by **Bowmar Instrument Corp.,** 8000 Bluffton Rd., Fort Wayne, Ind.



The Model X-1135 Gearhead features Bowmar's new "Postless" construction for greater shock and vibration resistance and lighter weight. A flange near the potentiometer is an integral part of the gearhead housing and is provided with three tapped holes for mounting the entire assembly into the system.

Maximum overall length, with motor and potentiometer as shown, is 3.780 inches. The gearhead with adapter and flanges is 1.250 inches long, and it weighs $1\frac{3}{4}$ ounces.

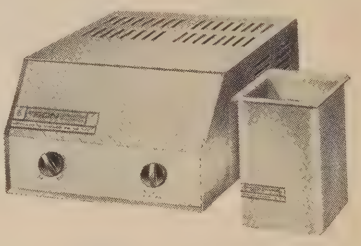
An anti-backlash arrangement may be provided on the potentiometer shaft to prevent lost motion of the unit by first assembling the gearhead to standard Bureau of Ordnance mounting holes on the size 11 motor. The potentiometer is then attached by means of standard Bureau of Ordnance type "dog" clamps.

Precision Class 2 gear tolerances per AGMA Specification 236.04 and Precision ABEC Class 5 or better ball bearings are used in the gearhead.

Additional details may be obtained from the firm.

Inexpensive Ultrasonic Cleaner

The introduction of a $99.95 ultrasonic cleaner, the diSONtegrator System Forty, by **Ultrasonic Industries, Inc.,** 141 Albertson Ave., Albertson, L.I., N.Y., will bring this equipment to a new group of users.



The System Forty, a half-gallon capacity model, is the lowest priced ultrasonic cleaner available anywhere in the world. It compares in power, cleaning tank capacity, performance and appearance with other ultrasonic cleaners now selling for up to ten times the price.

The System Forty will disintegrate more than fifty distinct classes of soils and contaminants in seconds from virtually thousands of different products ranging from surgical instruments, watches, clocks and false teeth to highly complex electronic components used in satellites and missiles.

The System Forty includes the Model G-40C1, a 40 watt generator with an output of 90,000 cps—a suitable frequency for small parts cleaning. The cabinet measures 10″ L. × 8″ W. × $5\frac{3}{4}$″ H. and features only one control knob—a simple push-pull activity regulation throttle. The diSONtegrator System Forty ultrasonic cleaner consumes no more current than an ordinary light bulb.

The generator powers the half-gallon capacity cleaning tank, Model T-4-C1, with working compartment measuring $5\frac{3}{4}$″ L. × $5\frac{1}{4}$″ W. × 4″ D. The overall dimensions are $6\frac{3}{4}$″ L. × $6\frac{1}{4}$″ W. × $6\frac{1}{2}$″ H. The tank is heavy gauge stainless steel deep drawn with rounded corners. It is finished with a 4A grade high polish to avoid soil entrapment in crevices or corners, thereby assuring surgical cleanliness.

(Continued on page 148A)

Creative Microwave Technology

Published by MICROWAVE AND POWER TUBE DIVISION, RAYTHEON COMPANY, WALTHAM 54, MASS., Vol. 2, No. 1

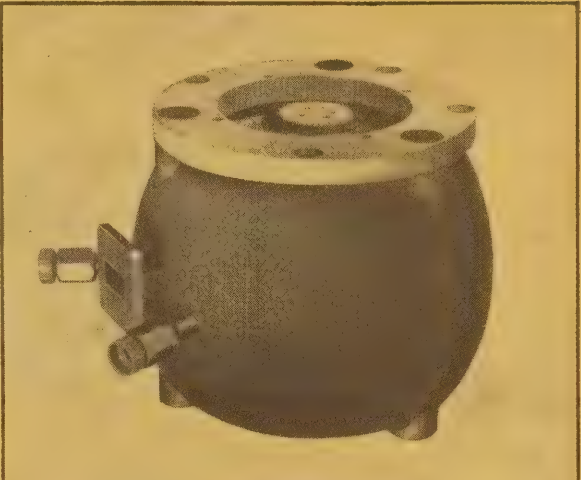
RAYTHEON "M"-TYPE BACKWARD WAVE OSCILLATORS

Electronically tunable at high power levels
for a wide range of microwave applications

Where extensive frequency mobility is required, the efficient crossed-field, "M"-type backward wave oscillator is highly versatile. Introduced more than eight years ago, it has been perfected by Raytheon and is now being economically mass produced. Hobbing of the slow-wave structure, a Raytheon-developed technique, assures precision construction necessary for consistently reproducible performance from tube to tube.

Typical of the "M"-type BWO's available from Raytheon is the QK-634A, an X-band tube which features all ceramic-and-metal construction for reliable operation under extreme environmental conditions.

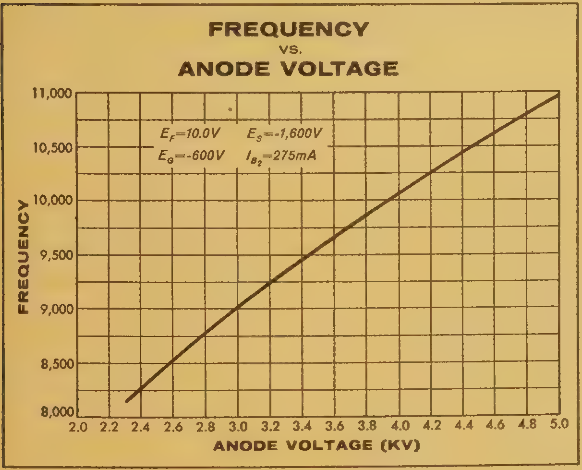
The QK-634A has a nominal power output of 200 to 250 watts and is electronically tunable over its entire frequency range. Precise determination of the radiated spectrum is accomplished by adjusting the voltage applied to either the anode or the sole. Amplitude modulation is also accomplished electronically. Small and compact, the QK-634A can be mounted in any position.

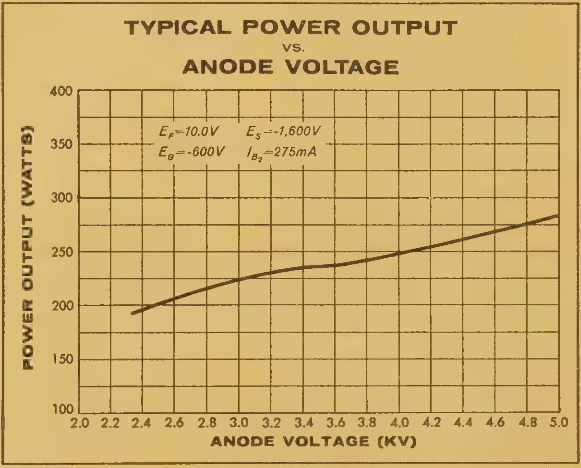


QK-634A Backward Wave Oscillator

Typical Operating Characteristics--QK-634A

Frequency Range	8,150 to 11,000 Mc
Power Output	150 watts (min.) 200 to 250 watts (nom.)
Output Flange	Mates with UG40A/U modified for clearance holes
Tuning Sensitivity	1.0 Mc/V





Other unclassified BWO's in this series include the QK-625 and QK-659, which cover the 2,500-4,450 Mc band.

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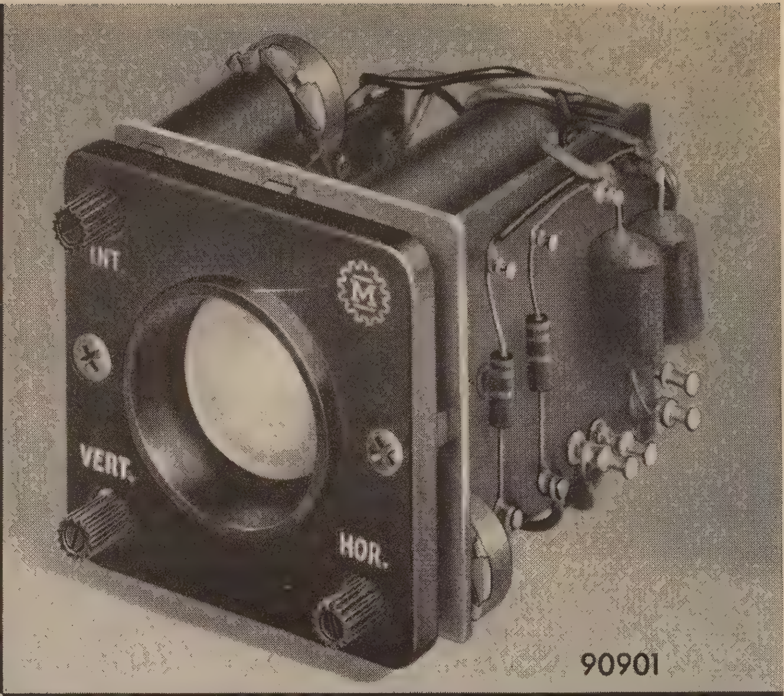
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INSTRUMENTATION OSCILLOSCOPE
One Inch
Miniaturized basic packaged panel mounting Cathode Ray Oscilloscope for instrumentation use replacing "Pointer Type" meters. Panel bezel matches 2" square meter. No. 90901 uses 1CP1 tube. No. 90911 uses 1EP1 tube. Power supply No. 90202 available where application requires.

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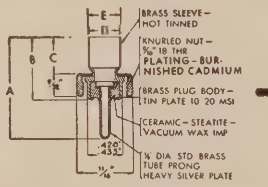
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PLATING—BURNISHED CADMIUM
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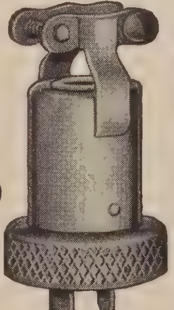
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LOW LOSS PLUGS AND SOCKETS FOR HIGH FREQUENCY CONNECTIONS

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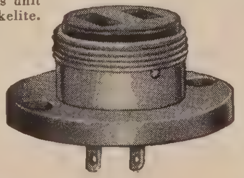
101 Series furnished with ¼", .290", 5/16", ⅜", or ½" ferrule for cable entrance. Knurled nut securely fastens unit together. Plugs have ceramic insulation; sockets bakelite. Assembly meets Navy specifications.

202 Series Phosphor bronze knife-switch type socket contacts engage both sides of flat plug contacts—double contact area. Plugs and sockets have molded bakelite insulation.

For full details and engineering data ask for Jones Catalog No. 22.

JONES MEANS *PROVEN* QUALITY

S-101


S-202-B

Jones
HOWARD B. JONES DIVISION
CINCH MANUFACTURING COMPANY
CHICAGO 24, ILLINOIS
DIVISION OF UNITED-CARR FASTENER CORP.

Professional Group Meetings

(*Continued from page 40A*)

Chicago—October 9

"Combined Antenna-Mixer-Filter Circuit," E. M. Turner, Wright-Patterson AFB.

Chicago—December 11

"Some Investigations Performed on an Ionospheric-Scatter Test Circuit," J. D. Ahlgren, Page Communications Engineers, Inc.

Los Angeles—January 14

"Power Handling of Antennas for High Altitude Operation," T. Morita, Stanford Res. Inst.

AUDIO

Chicago—September 11

"Loudspeaker Enclosure Walls," P. W. Tappan, Warwick Mfg. Corp.

Chicago—January 8

"Sound Vibrations in a Magnetostrictive Tube," R. R. Whymark, Armour Res. Foundation.

(*Continued on page 47A*)

SURVIVED INTACT!

an 18-story impact...

cushioned in urethane foam

Unbelievable? Not to the growing list of packaging engineers who are specifying urethane foam to protect expensive instruments, lenses, precision parts and fine tools from in-transit jars and jolts which often exceed G-forces in excess of an 18-story fall.

Urethane foam is the same material auto and aircraft makers use for shock-absorbing safety padding. Contour cut, die cut or molded in place, it is the most efficient impact-absorbing material yet invented.

The "Kudl-Pak,®" a precision part storage box used in this demonstration, is typical of the many versatile packaging ideas possible with lightweight, flexible or semi-rigid urethane foams. Cost is low; applications infinite!

Write Mobay Chemical Company for full details about urethane foam and sources of supply.

® Navan Products, Inc.

MOBAY CHEMICAL COMPANY
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Pittsburgh 5, Pennsylvania

Mobay is the leading supplier of quality chemicals used in the manufacture of both polyether and polyester urethane foams.

MOBAY
First in Urethane Chemistry

Sola Electric Co.

SOLA AC and DC voltage regulation

Continuous, automatic, maintenance-free

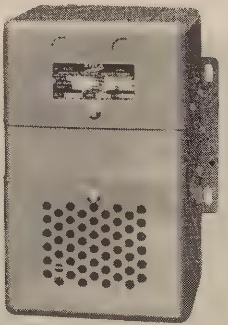
Sola Constant Voltage Transformers and Regulated DC Power Supplies provide dependable, regulated output voltage. Their output regulation is unaffected by wide variations in input voltage.

Sola CV Transformers are static-magnetic regulators with completely automatic, continuous regulating action. Their response to variations in input voltage is usually 1.5 cycles or less. They have no moving or renewable parts and require no maintenance.

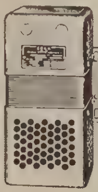
Each Sola Regulated DC Power Supply incorporates a constant voltage transformer in combination with a semi-conductor rectifier and a high-capacitance filter section. This combination makes the power supply compact, dependable, and efficient; and assures sustained output voltage in the face of pulse or intermittent loads, or heavy, short-time overloads.

Constant Voltage Transformers

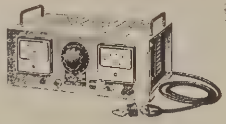
Sola Constant Voltage Transformers



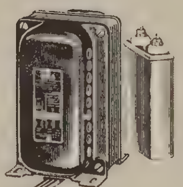
Standard Sinusoidal Type *provides voltage regulation of ±1% with primary voltage variations as great as ±15%. With less than 3% total rms harmonic content in their output voltage wave, these units are desirable for use with equipment having elements sensitive to power frequencies harmonically related to the fundamental. Available in nine ratings, 60va to 7.5kva.*



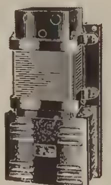
Normal-Harmonic Type *also provides ±1% regulation at somewhat less cost. This group has an average of 14% total rms harmonic content in its output voltages and is suited to equipment not extremely sensitive to voltage wave shape. The series includes those mechanical designs specially engineered for use as built-in components. Nineteen stock ratings range from 15va to 10kva.*



Adjustable Sinusoidal Type *provides ±1% regulated voltage output—one output adjustable from 0-130 volts and one fixed at 115 volts. Has less than 3% total rms harmonic content in output voltage. Portable for use in shop or laboratory, or mount on standard relay rack.*



Electronic Power Type *regulators provide ±1% regulated filament voltage at 6.0 and 6.3-volt levels; or a combination of plate and filament voltages regulated ±3% for ±15% input variations. Filament regulators are available in ratings from 2.3 to 25 amps. One model is specially designed for portable lab or shop bench use; it has a 30va rating. Combination plate/filament regulators, in three stock sizes, are designed to operate with commonly-used rectifier tubes.*



Custom-designed units *can be supplied in production quantities in ratings from 1va to 25kva to suit individual specifications. Custom designs can include special mechanical structures, various voltage ratios, special frequencies, compensation for frequency variations, multiple output voltages, three-phase service. Units can be manufactured to military specifications.*

Write for Circular 11-CV for additional information on Sola Constant Voltage Transformers

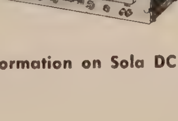
DC Power Supplies

Sola Constant Voltage DC Power Supplies

For intermittent...variable ...pulse...or high-current loads

Compact, rugged Sola Constant Voltage DC Power Supplies provide output regulated within ±1% over line voltage variations as great as ±10%. Their output contains ripple voltage of 1% total rms or less. They have exceedingly low output impedance. Output is in the "ampere" range. The high, short-time overload capacity handles intermittent and pulse loads without serious voltage drop or damage to components.

Fixed-output-voltage designs *are available in six stock models with ratings from 24v @ 6a to 250v @ 1a. They are extremely compact, light-weight, and moderately priced in proportion to their power output and performance.*



Adjustable-output designs *provide a considerable range of regulated dc test voltages. Accessory handles offer portability and permit self-stacking. Six models are available with outputs ranging from 5v @ 7a to 400v @ 0.6a.*

Write for Circular 11-DC for additional information on Sola DC Power Supplies

SOLA

BP
C

Sola Manufactures: Constant Voltage Transformers, Regulated DC Power Supplies, Constant Wattage Mercury Lamp Transformers and Fluorescent Lamp Ballasts

SOLA ELECTRIC CO. A Division of Basic Products Corporation

4633 West 16th Street, Chicago 50, Illinois, BIshop 2-1414 • In Canada, Sola Electric (Canada) Ltd., 377 Evans Avenue, Toronto 18, Ontario

Professional Group Meetings

(Continued from page 44A)

BROADCAST AND TELEVISION RECEIVERS

Chicago—September 11

"Cold Cathode Tubes for Commercial Receivers," A. M. Skellett, Tungsol Electric, Inc.

CIRCUIT THEORY

Chicago—October 9

"Review of Variable Reactance Amplifier Theory," L. L. Kocsis, Zenith Radio Corp.

COMMUNICATIONS SYSTEMS

Baltimore—December 8

"Statistical Communication Theory," H. Blasbalg, Electronic Communications, Inc.

Chicago—October 9

"The Sage UHF Communications Package," F. W. Griffith, II, Motorola, Inc.,

Chicago—December 11

"Some Investigations Performed on an Ionospheric-Scatter Test Circuit," J. D. Algren, Page Communications Engineers, Inc.

Los Angeles—December 8

"Digital Communications," C. Lindholm, Rand Corp.

"Digital Communications," R. Sanders, Space Electronics.

COMPONENT PARTS ·

Los Angeles—January 11

"A New Approach to the Organization of a Parts, Material & Process Operation," L. Jacobs, RCA.

ELECTRON DEVICES

Washington—January 18

"Status of Micro-Electronics," N. J. Doctor, Diamond Ordnance Fuze Labs.

ENGINEERING MANAGEMENT

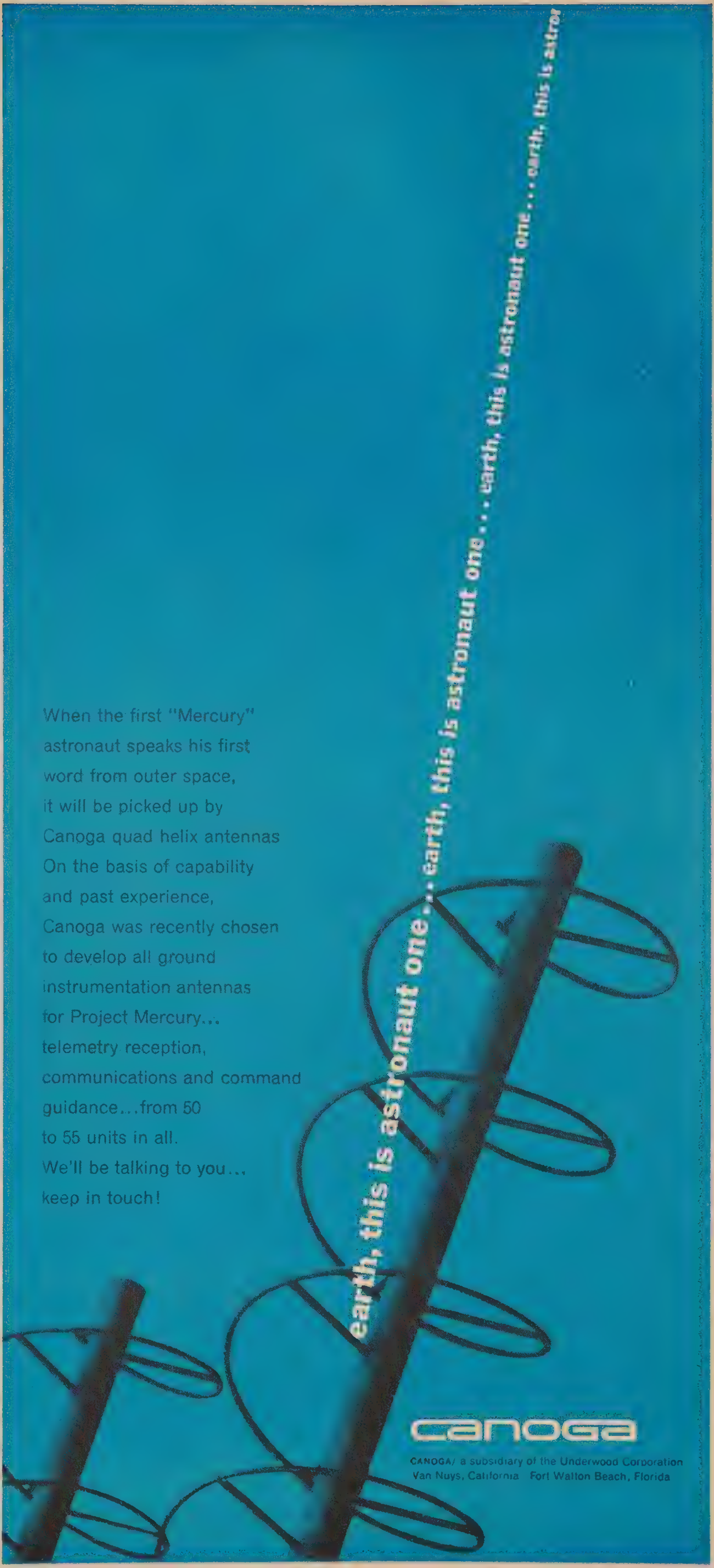
Chicago—November 13

"What Government and Industry Should Expect from Each Other," H. Neal, Cook Res.

Chicago—December 8

"The Future of the Electronics Industry," S. Weeks, Former Secretary of Commerce.

(Continued on page 48A)


earth, this is astronaut one... earth, this is astronaut one... earth, this is astronaut one... earth, this is astronaut one... earth, this is astro

When the first "Mercury"
astronaut speaks his first
word from outer space,
it will be picked up by
Canoga quad helix antennas
On the basis of capability
and past experience,
Canoga was recently chosen
to develop all ground
instrumentation antennas
for Project Mercury...
telemetry reception,
communications and command
guidance...from 50
to 55 units in all.
We'll be talking to you...
keep in touch!

canoga

CANOGA/ a subsidiary of the Underwood Corporation
Van Nuys, California   Fort Walton Beach, Florida

BENDIX SR RACK AND PANEL CONNECTOR

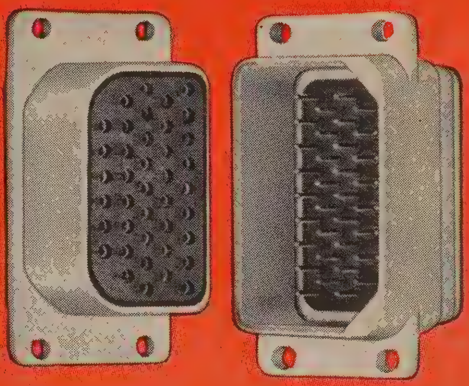
with outstanding resistance to vibration

The Bendix type SR rack and panel electrical connector provides exceptional resistance to vibration. The low engagement force gives it a decided advantage over existing connectors of this type.

Adding to the efficiency of this rack and panel connector is the performance-proven Bendix "clip-type" closed entry socket. Insert patterns are available to mate with existing equipment in the field.

Available in general duty, pressurized or potted types, each with temperature range of −67°F to +257°F.

Here, indeed, is another outstanding Bendix product that should be your first choice in rack and panel connectors.



FEATURES:

Resilient Insert • Solid Shell Construction • Low Engagement Forces • Closed Entry Sockets • Positive Contact Alignment Contacts—heavily gold plated Cadmium Plate—clear irridite finish • Easily Pressurized to latest MIL Specifications.

SCINTILLA DIVISION
SIDNEY, NEW YORK

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AVIATION CORPORATION

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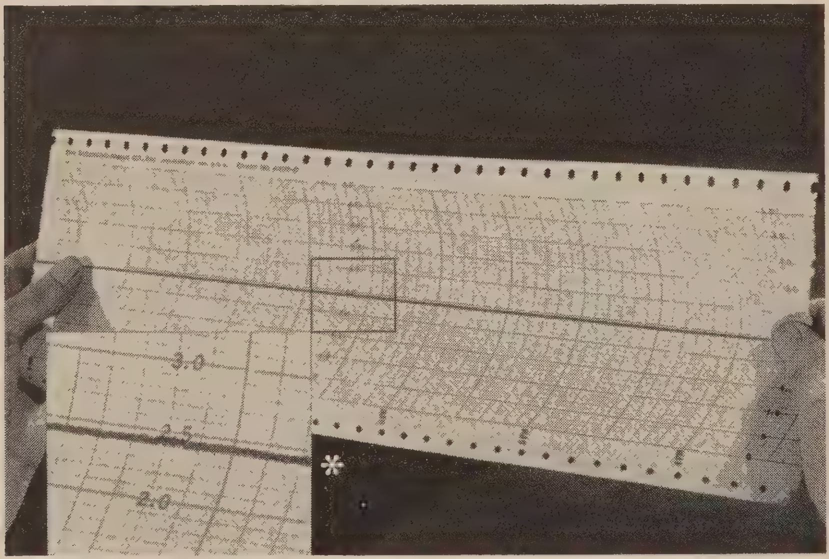
Canadian Affiliates: Aviation Electric Ltd., 200 Laurentien Blvd., Montreal 9, Quebec.
Factory Branch Offices: Burbank, Calif.; Orlando, Florida; Chicago, Illinois; Teaneck, New Jersey; Dallas, Texas; Seattle, Washington; Washington, D. C.



Measure fractions of a microvolt...approaching the Johnson noise limit... with Beckman DC Breaker Amplifiers. These high gain, low drift amplifiers are insensitive to vibrations, provide fast response and feed outputs directly to standard recorders. This means you can measure dc and low frequency ac voltages which were impossible or too tedious with devices like suspension galvanometers. A few applications include use with ultra-precision bridge circuits for measurement of differential thermocouples, nerve voltages, and other extremely low voltages. For detailed specifications write for Data File 9-4-11.

Beckman
Scientific and Process Instruments Division
Beckman Instruments, Inc.
2500 Fullerton Road, Fullerton, California

INSTRUMENTAL IN YOUR FUTURE 25 YEARS 1935-1960

**Note low noise level...less than .003 microvolt*

Professional Group Meetings

(Continued from page 47A)

INSTRUMENTATION

Washington—January 11

Panel Discussion on "The Next Ten Years in Instrumentation," S. N. Alexander, NBS; R. L. Bowman, National Heart Institute of NIH; T. MacAnespie, Glen L. Martin Co.

MEDICAL ELECTRONICS

Boston—December 8

"Digital Computer Techniques in the Study of the Nervous System," W. A. Clark, Lincoln Lab. M.I.T.

Boston—January 26

"Engineering for Surgery," J. J. Baruch, Bolt, Beranek and Newman.

Chicago—December 11

"The Clinical Quantitation of Tone and Tremor," J. Brumlik, M.D.; H. Wachs, M.D.; B. Boshes, M.D.; M. L. Petrovick, B.S.E.E.; Northwestern University Medical School.

(Continued on page 50A)

The Most Complete Line of

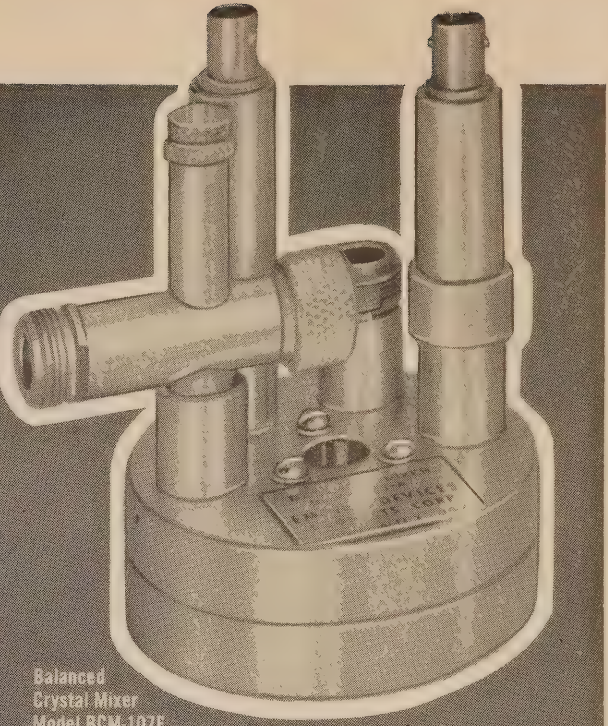
COAXIAL BROADBAND CRYSTAL MIXERS

We have the answers to many unique coaxial mixer design requirements.

• Broadbanding • Low VSWR • Unusual Frequency Combinations • Low-Noise Design • R.F.-L.O.-I.F. Isolation.

The expanded line of coaxial mixers from EMPIRE represents the solution to these, and many other problems. Most types are available for immediate delivery from stock.

WHAT IS YOUR SPECIAL PROBLEM?

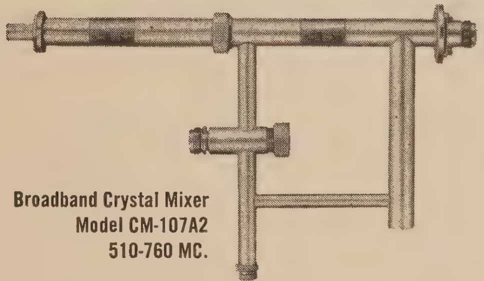


Balanced
Crystal Mixer
Model BCM-107E
2500-2900 MC.

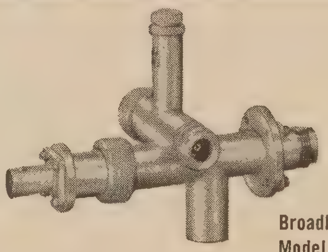
BALANCED MIXERS, Model BCM-107

For R.F. frequencies from 1000 to 5600 MC.
Models for push-pull or single-ended I.F. inputs.
Featuring, over a 15% bandwidth:

- ★ Input VSWR less than 1.5 to 1, without adjustment.
- ★ L.O. noise cancellation at least 20 DB.
- ★ Isolation between R.F. and L.O. at least 20 DB.
- ★ L.O. rejection at I.F. terminals at least 30 DB.



Broadband Crystal Mixer
Model CM-107A2
510-760 MC.



Broadband Crystal Mixer
Model CM-107F
4000-5600 MC.

BROADBAND MIXERS, Model CM-107

For R.F. frequencies from 225 MC to 8200 MC.
Featuring over a broad range of frequencies:

- ★ Input VSWR less than 2 to 1, without adjustment.
- ★ L.O. VSWR less than 2 to 1, without adjustment.
- ★ L.O. rejection at I.F. output, better than 30 DB.
- ★ L.O. power requirements 10 MW, with adjustable injection feature.

For complete data, send for Catalog 604.

edp **EMPIRE DEVICES PRODUCTS CORP.**
AMSTERDAM, NEW YORK
VICTOR 2-8400

MANUFACTURERS OF:
FIELD INTENSITY METERS • DISTORTION ANALYZERS • IMPULSE GENERATORS • COAXIAL ATTENUATORS • CRYSTAL MIXERS

*** What's Behind This?**

a major advance in the state of infrared art
by HRB-SINGER, INC.

At long last HRB is permitted to admit openly their relationship to the revolutionary "Manhattan Strip," taken with IR equipment developed at HRB-SINGER. The map-like image was photographed under conditions of complete darkness. Amazingly clear, accurate and continuous data of the Manhattan terrain resulted.

IR surveillance equipment which meets military requirements, is continually being developed and improved at HRB-SINGER. Although RECONOFAX, the trade name applied to HRB IR equipment has been employed primarily in aircraft, it could be used in other vehicles such as satellites for scanning areas several hundred miles wide.

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ELECTRONIC RESEARCH AND DEVELOPMENT in the areas of:

Communications • Countermeasures • Reconnaissance • Human Factors • Intelligence • Weapons Systems Studies and Analysis • Nuclear Physics • Operations Research • Antenna Systems • Astrophysics

HRB

HRB-SINGER, INC.
A SUBSIDIARY OF THE SINGER MANUFACTURING COMPANY
Science Park, State College, Pa.

SINGER MILITARY PRODUCTS DIVISION

Professional Group Meetings

(Continued from page 48A)

MILITARY ELECTRONICS

Chicago—October 9

"The SAGE UHF Communications Package," F. W. Griffith, II, Motorola, Inc.

Chicago—November 13

"What Government and Industry Should Expect from Each Other," H. T. Neal, Cook Electric.

Indianapolis—December 10

Election of Officers.

Northwest Florida—December 15

"Recent Biological Experiments in Ballistics Missiles," D. E. Stullken, Naval Air Station.

Philadelphia—January 19

"Sonic Detection Techniques," J. Howard and H. West, Naval Air Dev. Center.

PRODUCTION TECHNIQUES

Boston—January 12

"Numerical Control and its Use in Industry Today," H. P. Kilroy, Concord Control, Inc.

Philadelphia—January 20

"Molectronics," G. Strull, Westinghouse Electric Co.

"Micro-Modules," J. Wentworth, RCA.

"Integrated Electronics," R. Lee, Texas Instruments, Inc.

SPACE ELECTRONICS AND TELEMETRY

Philadelphia—January 20

"Molectronics," G. Strull, Westinghouse.

"Micro-Modules," Mr. Wentworth, RCA.

"Micromolecular Circuits," R. Lee, Texas Instruments.

Washington—November 17

"Electrical Propulsion for Space Missions," W. Moeckel, Lewis Res. Centr. NASA.

VEHICULAR COMMUNICATIONS

Los Angeles—January 21

"MT-59 ITT Mobile Telephone Equipment Design and Operation," K. Haase, International Telephone & Telegraph Co.

Use Your
IRE DIRECTORY!
It's Valuable

NEW ... FROM INDUSTRY'S BROADEST RECTIFIER LINE

SILICON CARBIDE RECTIFIERS

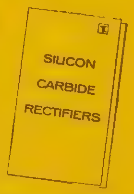
FEATURES

- IMPROVED RELIABILITY AT ELEVATED TEMPERATURES
- HIGHER TEMPERATURE PERFORMANCE TO 500°C
- EXCELLENT RADIATION RESISTANCE

Silicon carbide rectifiers are now available for production requirements. Their inherent higher temperature capabilities (to 500°C) provide greater reliability in existing circuitry subject to high ambient temperatures. Resistance to radiation is up to 100 times greater than previously available in any semiconductor rectifiers.

	SPECIFICATIONS @ 500°C.			RATINGS @ 500°C.	
Type	Peak Inverse Voltage (volts)	Maximum Inverse Current I_b (μa)	Maximum Forward Voltage @ Specified Current (volts @ mA)	Maximum Average Forward Current I_o (mA)	Maximum Peak Inverse Voltage (volts)
TCS10	100	500	6 @ 100	100	100
TCS5	50	500	4 @ 100	100	50

	SPECIFICATIONS @ 25°C.		
Type	Peak Inverse Voltage (volts)	Maximum Inverse Current I_b (μa)	Maximum Forward Voltage @ Specified Current (volts @ mA)
TCS10	100	10	12 @ 100
TCS5	50	10	8 @ 100



Write for Bulletin PB-70

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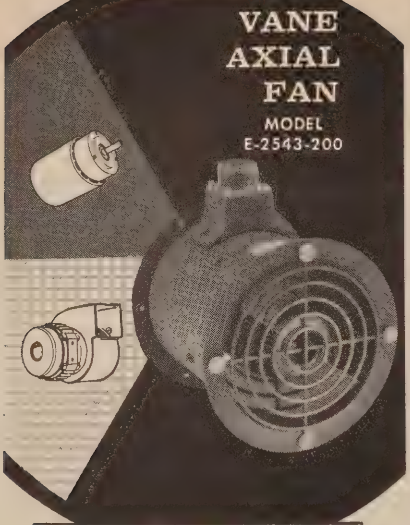
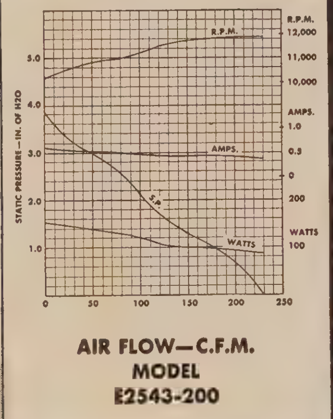
"Leadership in Semiconductors" SEE YOUR LOCAL AUTHORIZED TRANSITRON DISTRIBUTOR FOR QUANTITIES FROM 1-999.





SPECIFICATIONS:
200V 400 cps 3 phase
200 CFM at 3/4" S.P.
Weight: 3 lb. 8 oz.
Ambient: 85°C
Life: 5000 hrs.
Environmental MIL-E-5422D
Material MIL-E-5400B
Class F Insulation

Our Field Engineers will gladly assist you in your cooling problems

Air-Marine motors and cooling units have been designed and tested to meet the specifications of both the military and industry.

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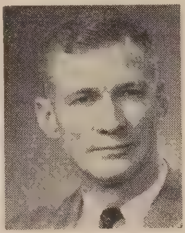
WRITE TODAY FOR OUR NEW CATALOG

IRE People

The appointment of **Gordon C. Berry** (S'43–A'47) as regional sales engineer for receiving tubes has been announced by C. Byron Farmer, southeastern regional sales manager of the General Electric Receiving Tube Department.



G. C. Berry

In his new position, Mr. Berry will provide engineering liaison with both manufacturers of electronic equipment and with users of equipment in the commercial and industrial electronics field. For several years he has served as a district engineer working out of Atlanta on two-way radio, microwave, and broadcasting engineering assignments.

A native of Huntsville, Ala., he is a graduate of Georgia Institute of Technology from which he received the B.S. degree in electrical engineering in 1947. During World War II he served as a first lieutenant in the Army Signal Corps.

Mr. Berry is a member of the National Society of Professional Engineers.

❖

Glen P. Bieging (M'56) with 20 years' experience as an executive in military and industrial electronics, has joined Packard Bell Electronics Corp. as vice president, marketing, of the company's new Defense and Industrial Group, it was announced by Richard B. Leng, group vice president.

G. P. Bieging

For the last five years Mr. Bieging has been associated with General Electric as manager of product planning for the Heavy Military Electronics Department in Syracuse, N. Y., and as manager of marketing for the Missile and Space Vehicle Department, Defense Electronics Division, Philadelphia.

He served as an electronics officer in the U. S. Air Force from 1940–50, resigning with the permanent rank of major. During the Korean conflict he spent one year as civilian consultant to the Deputy Chief of Staff, Development, Headquarters USAF, then moved to Raytheon Manufacturing Co., Waltham, Mass., as assistant to the vice president for engineering and research. He subsequently served as salesmanager of Lavoie Laboratories, Morganville, N. J., and operated his own company in the electronics export field.

At Packard Bell Electronics, he will direct marketing and product planning for the Defense and Industrial Group which comprises the Technical Products Division, Packard Bell Computer Corp. and Physical Sciences Corp., a subsidiary formerly known as Technical Industries Corp.

Mr. Bieging holds a B.S. degree in business and engineering from the University of Minnesota and was graduated from the British Military College of Science. He also attended the Air Command and Staff School and the Air Communications and Electronic Staff Officers School. He is a member of the American Ordnance Association, Air Force Association, American Society of Naval Engineers and the Armed Forces Communications Electronics Association.

❖

The New York Academy of Science announced the award to the grade of Fellow to **Roland C. Bostrom** (S'49–A'50–M'55) for his work in the field of Medical Electronics.

A supervisor in the Department of Medical and Biological Physics of Airborne Instruments Laboratory, Deer Park, N. Y., he is known for his work on the Cytoanalyzer, an electronic instrument that detects cancer in the shed cells of the body by means of the Papanicolaou smear test.

The Cytoanalyzer is presently under evaluation at The National Cancer Institute of Health, Hagerstown, Md. and the Sloan Kettering Institute, New York, N. Y. This equipment has been designed to detect cancer of the uterus by scanning microscope slides bearing the specimen cells.

❖

H. Thomas Bean (M'57), Vice-President of Telecomputing Services, Inc., and General Manager of their data reduction operations at White Sands Missile Range has been elected Chairman of the Executive Committee of the Holloman Test Directors Council at the Air Force Missile Development Center, N. M.

In addition to his duties as Administrator of the data reduction facility at Holloman Air Force Base, he is chairman of the Management Committee, Data Reduction Group, IRIG; and chairman of the New Mexico Advisory Committee on Scientific, Engineering and Specialized Personnel.

Mr. Bean received the B.S. degree in physics from Thiel College. He also has been an instructor in physics at Thiel College, Chief Physicist for the 7th Naval District, Chief of Data Reduction at Eglin Air Force Base, and a member of the Technical Staff, Space Technology Labs before joining TSI in his present capacity.

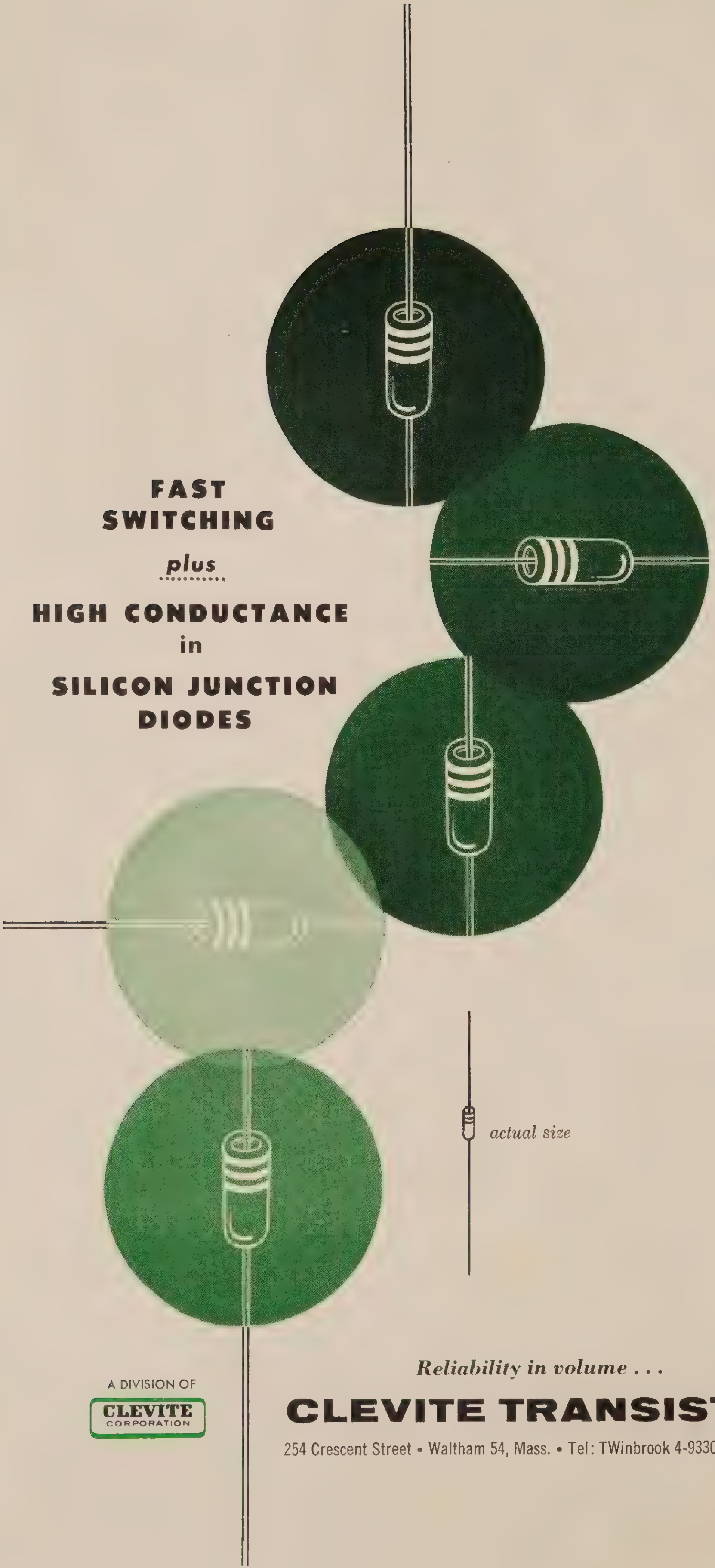
He is a member of the American Rocket Society and Instrument Society of America.

❖

(Continued on page 56A)

Reliability in volume...

CLEVITE
TRANSISTOR
WALTHAM, MASSACHUSETTS



FAST SWITCHING

plus

HIGH CONDUCTANCE

in

SILICON JUNCTION DIODES

SWITCHING TYPES

New circuit possibilities for low impedance, high current applications are opened up by Clevite's switching diodes. Type CSD-2542, for example, switches from 30 ma to −35v. in 0.5 microseconds in a modified IBM Y circuit and has a forward conductance of 100 ma minimum at 1 volt.

Combining high reverse voltage, high forward conductance, fast switching and high temperature operation, these diodes approach the ideal multi-purpose device sought by designers.

GENERAL PURPOSE TYPES

Optimum rectification efficiency rather than rate of switching has been built into these silicon diodes. They feature very high forward conductance and low reverse current. These diodes find their principal use in various instrumentation applications where the accuracy or reproduceability of performance of the circuit requires a diode of negligible reverse current. In this line of general purpose types Clevite has available, in addition to the JAN types listed below, commercial diodes of the 1N482 series.

MILITARY TYPES

JAN

1N457	MIL-E-1/1026
1N458	MIL-E-1/1027
1N459	MIL-E-1/1028

Signal Corps

1N662	MIL-E-1/1139
1N663	MIL-E-1/1140
1N658	MIL-E-1/1160
1N643	MIL-E-1/1171

All these diodes are available for immediate delivery. Write now for Bulletins B217A-1, B217A-2 and B217-4.

Phone for data and prices.

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- *Highest accuracy!*
- *Widest range!*

BATTERY MINIMUM
POWER MILLIWATTS
DECIBELS
the narda
microwave corporation
POWER METER
NARDA MODEL 440

NARDA transistorized POWER METER

MODEL 440 **. . . $250**

What's most important to you in a power meter? Accuracy? Portability? Independence from line voltage deviations? Wide range? Stability? Rapid warm-up?

Not that you have to make a choice . . . or a compromise . . . any longer. The Narda Model 440 Power Meter gives you **all** these features! Completely transistorized and powered by a nickel-cadmium battery, rechargeable during operation or overnight, it offers two low-power scales in addition to the five standard scales (see below), a built-in charger with state-of-charge indicator and protection against overcharging, and freedom from internal heating caused by vacuum tubes.

Moreover, the 440 provides up to 18 ma bias current, enabling you to use the widest selection of bolometers and thermistors. In short, the 440 is the most versatile unit available to provide accurate direct-reading measurements of cw or pulsed-power automatically, over any frequency range for which there are bolometer or thermistor mounts. For complete data, contact your nearest Narda representative, or write us directly. Address: **Dept. PIRE-11.**

SPECIFICATIONS

POWER RANGES: 7 SCALES

***0.01 mw full scale**	−30 to −20dbm
***0.03 mw full scale**	−25 to −15dbm
0.1 mw full scale	−20 to −10dbm
0.3 mw full scale	−15 to −5dbm
1.0 mw full scale	−10 to 0dbm
3.0 mw full scale	−5 to +5dbm
10 mw full scale	0 to +10dbm

*4.5 ma bolometers give best results on these scales.

Range Switch: 0.01 to 10 mw (full scale)

Accuracy: 3% of full scale reading

Bolometers & Thermistors: All 100 and 200 ohm, requiring up to 18 ma bias.

Battery Charger: Built-in; continuous or overnight. (Battery operable 16 hrs. before recharge required.)

the narda microwave corporation

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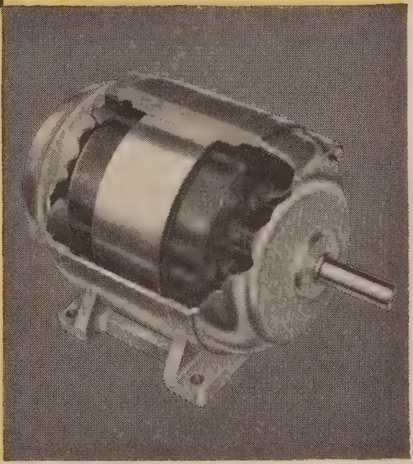

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For over a decade HYSOL chemists and engineers have been helping manufacturers solve unique and intricate problems of insulation. As a result of this experience, Hysol has developed a complete line of epoxy encapsulating compounds. For superior insulation, for outstanding moisture, chemical and abrasion resistance, for dependable performance . . . there's a Hysol epoxy to meet your specifications. Write for the HYSOL "Systems Selector."

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Los Angeles, California

HYSOL (CANADA) LTD.
Toronto, Ontario

IRE People

(Continued from page 52A)

Dr. P. S. Christaldi (S'35–A'40–SM'44–F'52) has joined G-V Controls Inc. of Livingston, N. J. as Manager of Engineering. He has been, since 1956, Product Manager, Nuclear Systems, for Curtiss-Wright Corp. Prior to that he was associated for eighteen years with Allen B. DuMont Laboratories, Inc.

P. S. Christaldi

His appointment represents the first move in a program of expansion and diversification planned by G-V Controls, following the company's move into a newly constructed plant in Livingston. Present products include thermal relays, electrical thermostats, transistorized time delays, and wired control assemblies.

Dr. Christaldi is past Chairman of the Northern New Jersey Section of the IRE, and the author of a number of papers in the electronic field and of the section on Oscilloscopes and Electronic Switching of the McGraw-Hill Industrial Electronics Handbook.

❖

Frank K. Clark Jr. (S'48–A'51–M'56) has been appointed chief engineer of the M. C. Jones Electronics Co., Inc., it was announced by George E. Steiner, president of the Jones company and general manager of the Scintilla division of Bendix Aviation Corporation.

The Jones company, a subsidiary of Bendix, manufactures test equipment for monitoring radio frequency coaxial transmission lines.

Clark joined the Bendix Radio division in Baltimore in 1954 and worked on the development of high-powered radio transmitters and microwave tube applications. Previously he was with Electro Precision Products, Inc. and Hazeltine Electronics Corporation.

He is a member of the American Ordnance Association. In 1958 he served as secretary-treasurer of the Baltimore section of the IRE and in 1959 was vice chairman. He is a 1950 graduate of the University of Texas with a B.S. degree in electrical engineering.

❖

The promotion of **Paul W. Crapuchettes** (M'44–F'60) to Technical Director of the Litton Industries Electron Tube Division was announced recently by Dr. Norman Moore, Division General Manager.

In addition to this Senior staff position, he is also Manager of the Magnetron Product Line.

Mr. Crapuchettes was formerly Chief Engineer for the Electron Tube Division. He has been associated with the Litton In-

(Continued on page 58A)

AN ACHIEVEMENT IN DEFENSE ELECTRONICS

WHAT'S BEHIND A BMEWS RADAR?

Years of experience—for as early as 1954, General Electric had conceived and developed radar equipment capable of detecting ballistic missiles at 1,000 miles. This was the forerunner of the AN/FPS-50 surveillance radar being provided by General Electric under subcontract to RCA for the Air Force Ballistic Missile Early Warning System (BMEWS).

The AN/FPS-50 radar equipment, with a range in excess of 2,000 miles, is a singular example of achievement in defense electronics. It is another milestone in General Electric's sustained engineering effort to develop and produce equipment to meet the unprecedented detection problems posed by ICBM's. 176-01

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DEFENSE ELECTRONICS DIVISION
HEAVY MILITARY ELECTRONICS DEPARTMENT
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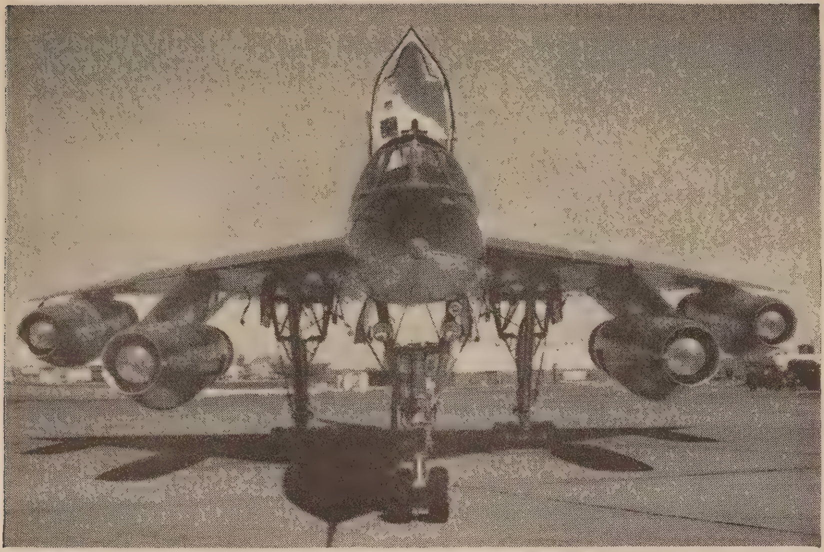


The B-58 Hustler, America's first supersonic bomber, is now in production for the U. S. Air Force at the Fort Worth, Texas, Plant of the Convair Division of General Dynamics Corporation. Carrying a crew of only three, the B-58 is designed to operate at altitudes above 50,000 feet and is powered by four General Electric J79 turbojet engines.

Sprague Awarded Contract For Engineering Assistance On B-58 Hustler

The abundance of electronic equipment fitted into the small, dense, supersonic B-58 Hustler calls for comprehensive interference control engineering. To obtain on-the-spot assistance for this extremely complex engineering problem, the Weapon System Manager for the Mach 2 bomber at Convair's Fort Worth Plant has awarded a special contract to the Interference Control Field Service Department of the Sprague Electric Company.

Under the terms of the contract Sprague will assist Convair with the integration of both electrical and electronic equipment of airborne and ground systems into an even more effective and reliable weapon system. Sprague staff engineers assigned to the project are already at work at the Fort Worth Plant.

Sprague Interference Control Laboratories located in Dayton, Los Angeles, and North Adams, are supporting the Convair program as testing and sampling facilities. These laboratories are staffed by top interference and susceptibility control specialists, and are equipped with the most advanced instrumentation and model shop facilities.

For assistance with your Interference, Susceptibility, and Integration problems, write Interference Control Field Service Manager, Sprague Electric Co. at 12870 Panama Street, Los Angeles 66, California; 224 Leo Street, Dayton 4, Ohio; or 235 Marshall Street, North Adams, Massachusetts.

IRE People

(Continued from page 56A)

dustries Engineering Department since 1946. Mr. Crapuchettes was graduated from the University of California in 1940.

❖

Alan F. Culbertson (A'55–SM'56) has been appointed Director of Engineering at Lenkurt Electric Co., Inc., San Carlos, Calif.

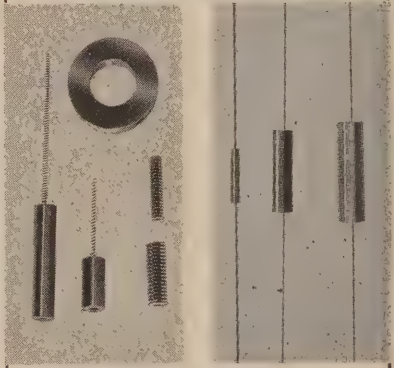
A. F. Culbertson

He will be responsible for development of telecommunications and allied systems for commercial and government use, as well as for supporting engineering activities including component development and quality control.

He has been with Lenkurt, a subsidiary of General Telephone and Electronics, since 1952 when he was employed as an applications engineer. He later was manager of transmission engineering and of product planning. For the past year and a half he has headed the mobile telephone group which has developed and marketed new systems for vehicular telephone service.

(Continued on page 60A)

KRYSTINEL FERRITES



K-202 FERRITE CORES

Now in production quantities, this ferrite material designed especially for use as choke cores, tuning cores, threaded cores, cup cores, in 30 kc. to 3 mc. frequency range.

- excellent magnetic properties
- stable shock and aging characteristics
- low permeability drift with respect to temperature . . . consistently uniform

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KRYSTINEL CORP.

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Delay lines at ESC are now scheduled, produced and inspected under the control of a completely automated, electronic IBM Integrated Data Processing System. The new system enables ESC to know, within minutes, the status of every delay line order. Vital delivery information can now be presented with greater precision. Statistics, now immediately available on production runs, serve as invaluable tools in maintaining a consistently high quality level. Thus, a new dimension in quality and flow control is added to exceptional research, production and inspection facilities; more reasons why the world's leading manufacturer of custom-built and stock delay lines is . . .

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exceptional employment opportunities for engineers experienced in computer components . . . excellent profit-sharing plan.

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Crystals are grown by a modified Czochralski technique.

Large Diameter
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INFRARED
Cut Domes and Lenses

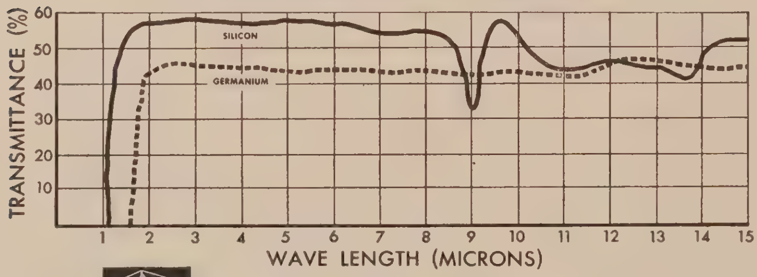
Silicon cut domes and lenses to 8″ diameter, with IR transmission to 97% (coated), are now available in production and evaluation quantities. Diameters up to 19″ will be available in the near future.

These significantly larger diameters can now be grown as a result of recent Knapic research and experimental growing programs. Temperature gradient, pressure, and impurity evaporation controls, as well as unique growing methods, are the result of original Knapic laboratory work.

Germanium lenses and domes are also available

SPECIFICATIONS	SILICON	GERMANIUM
• Hardness	750-2000 (Knoop) Excellent	692 (Knoop) Excellent
• Index of Refraction	3.50 high	4.10 high
• Melting point	1420°c Excellent	958°c Fair
• Density	2.3 gm/cm³	5.34 gm/cm³
• Ease of finishing	Excellent—very hard	Good
• Transmission cut-off	About 20 microns Excellent	About 23 microns Excellent
• Reaction to Thermal Shock	Good	Good
• Thermal conductivity	Excellent	Excellent

TYPICAL INFRARED TRANSMISSION CHARACTERISTICS OF UNCOATED KNAPIC-GROWN SILICON AND GERMANIUM



Also manufacturer of Silicon and Germanium crystals for solar cell and semi-conductor devices.

Write for specifications sheet

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Western—204 South Beverly Drive, Beverly Hills, California • Phone CR 6-7175
European—#2 Prins Frederick Hendriklaan, Naarden, Holland • Phone K 2959-8988

IRE People

(Continued from page 58A)

Previously, he spent six years with American Telephone and Telegraph's Long Lines Dept. in transmission and equipment engineering positions. In the Navy he served as a communications and electronics officer.

Mr. Culbertson received the B.S.E.E. degree from Purdue University. He is a member of the American Institute of Electrical Engineers and Eta Kappa Nu. He is the author of many papers and articles on telecommunications.

❖

D. A. Dunn

Dr. Donald A. Dunn (S'46–A'52–SM'56) has been named Director of the newly formed Research Division of Eitel-McCullough, Inc., manufacturer of Eimac electron-power tubes.

The new division, consolidating into an expanded program many Eimac research activities, will headquarter in San Carlos, Calif. Conducting new and advanced technological research in present and new areas of company interest, it will contribute new technical knowledge to the product development programs of Eimac and its subsidiaries, according to Executive Vice President Gould Hunter.

Dr. Dunn, a senior research associate and lecturer in the electrical engineering department of Stanford University, joined Eimac in 1959 as manager of the Supporting Research Group. He holds the B.S. degree from California Institute of Technology, class of 1946. In addition, he received the M.S. and Ph.D. degrees in Electrical Engineering and an LL.B. from Stanford.

He is currently vice-chairman of the San Francisco Section of the Institute of Radio Engineers and is former chairman of the San Francisco Chapter of the Professional Group on Electron Devices.

❖

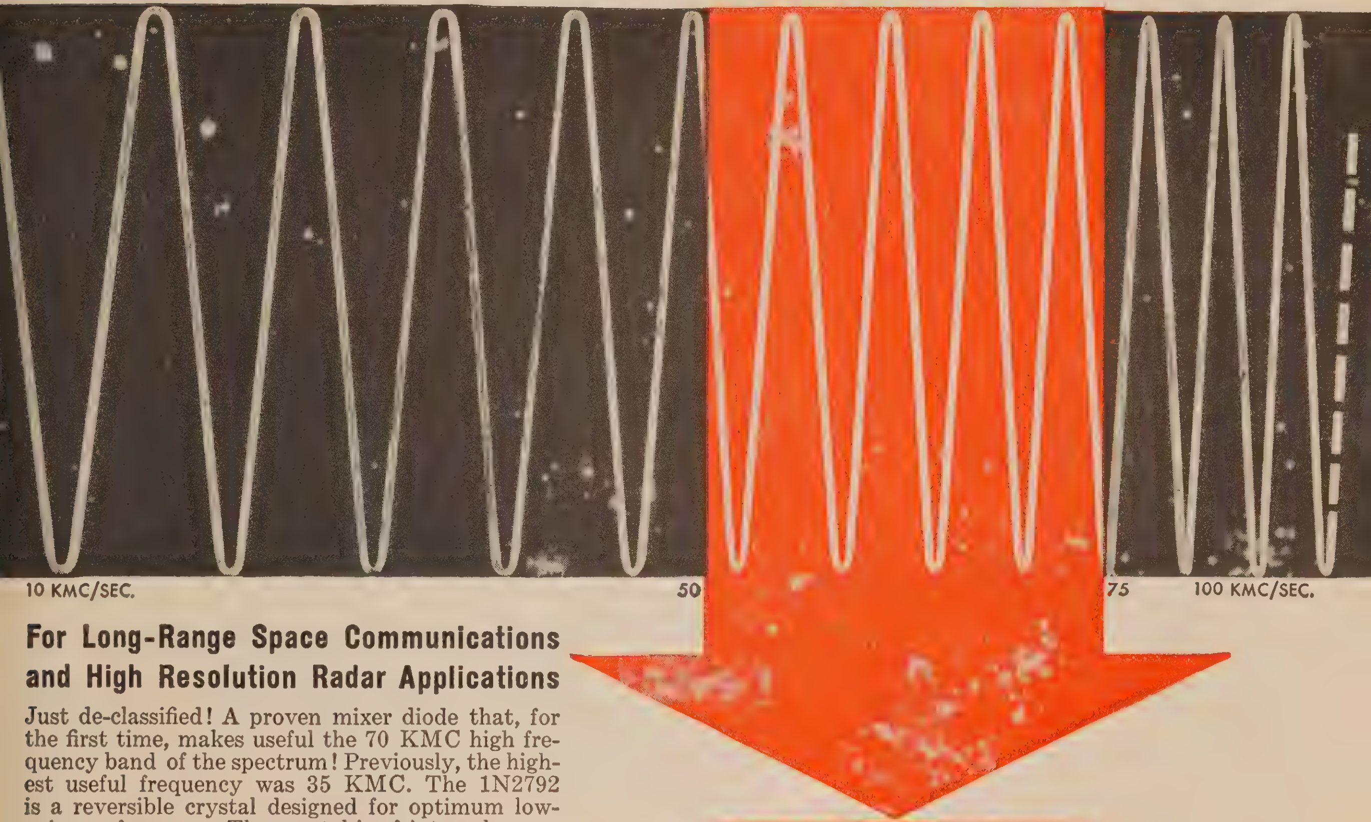
A. P. Fontaine, executive vice president of Bendix Aviation Corporation, has announced the appointments of **Charles M. Edwards** (S'41–A'43–M'45–SM'53) as his assistant and **Dr. G. A. Rosselot** (A'41–M'55) as assistant general manager and associate director of the Research Laboratories division of the company.

Mr. Edwards, formerly assistant director in charge of technical activities of the Research Laboratories division, will be mainly responsible for new product development at the corporate level, in addition to assisting Mr. Fontaine in other corporation activities, including engineering and research, sales, and patent activities.

In 1951 he joined the staff of the Research Laboratories division as a project engineer in charge of the development of

(Continued on page 62A)

Now...PHILCO offers the only commercially available fully-tested mixer diode in the 70 KMC BAND


10 KMC/SEC.
50
75
100 KMC/SEC.

For Long-Range Space Communications and High Resolution Radar Applications

Just de-classified! A proven mixer diode that, for the first time, makes useful the 70 KMC high frequency band of the spectrum! Previously, the highest useful frequency was 35 KMC. The 1N2792 is a reversible crystal designed for optimum low-noise performance. The crystal is of integral waveguide construction with the diode mounted in a section of RG-98/U waveguide. It is hermetically sealed for resistance to moisture.

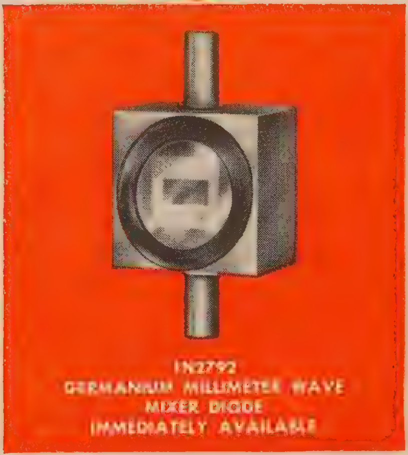
It is primarily designed for high resolution radar applications and for long-range high altitude or space communications . . . atmospheric absorption prevents jamming from the ground. The Philco 1N2792 is also well suited for EHF video detector applications.

Philco design and application facilities are at your disposal in developing millimeter diodes to meet your specific requirements. For complete information, write Special Components Dept. IR 460.

Test Frequency..........................69,750mc

	TYP.	MAX.	
Noise Ratio, NRo..............	2.0	2.5	times
Conversion Loss, Lc (Note 1).....	8.4	10	db
RF Impedance, VSWR..........	1.35	2.0	times
Crystal noise figure, NF (Note 1)..	11.5	13	db

Note 1: Based on a noise temperature of 5800° K for Roger White Noise Source No. GNW-V18.



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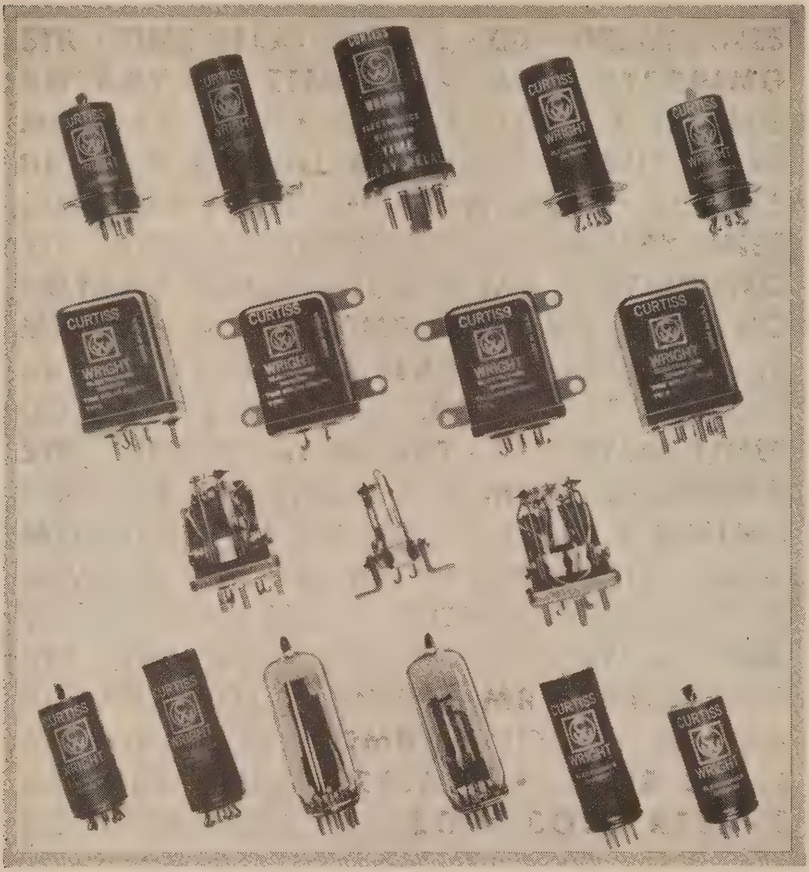
Time Delay Relays

DESIGNED FOR YOUR APPLICATIONS



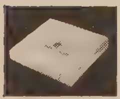
As represented above, Curtiss-Wright is manufacturing Time Delay Relays for your special applications. Included among the features are:

Instantaneous resetting contacts • Chatter-free operation
Voltage and High Temperature compensation • Snap action
Hermetically sealed • Resistance to severe shock and vibration
Multiple load contacts

Our application engineers are available to assist you with your individual time delay requirements. Many of the features indicated above are presently included in our standard relay line.

WRITE FOR COMPONENTS CATALOG 260 A

ULTRASONIC DELAY LINES Curtiss-Wright produces Magnetostrictive Delay Lines featuring delays from 5 to 12,000 microseconds, small size, hermetically sealed, and light in weight. Delay lines are designed to meet your application.



COMPONENTS DEPARTMENT • ELECTRONICS DIVISION
CURTISS WRIGHT
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TIME DELAY RELAYS • DELAY LINES • ROTARY SOLENOIDS • DIGITAL MOTORS • TIMING DEVICES • DUAL RELAYS • SOLID STATE COMPONENTS

IRE People

(Continued from page 60A)

the analog computer and control equipment for the Bendix three-dimensional flight systems simulator. In 1955 he was named to head the computer department of the division.

He received the B.S. and M.S. degrees in electrical engineering from Massachusetts Institute of Technology, and for five years supervised graduate students at M.I.T. He is a member of the Engineering Society of Detroit.

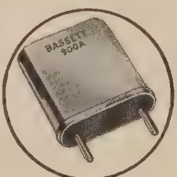
Dr. Rosselot, formerly assistant director in charge of administration of the Research Laboratories division, joined the staff of the Bendix Products division, missile section, in 1953, as staff assistant and director of engineering. For three years, before being appointed to the staff of the Research Laboratories division, he was director of university and scientific relations for the Corporation.

From 1934 to 1953 he was associated with the Georgia Institute of Technology as director of research. In 1936 he received the Ph.D. degree in physics from Ohio State University. He is a graduate (cum laude) of Otterbein College. He is a member of The American Society for Engineering Education, and the Engineering Society of Detroit.

❖

(Continued on page 64A)

DEPENDABLE FREQUENCY CONTROL



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35 TO 250 AMPS

35 amps
100 amps
150 amps
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Tarzian high-current line combines thermal efficiency with mounting versatility and optional base polarity

The low junction current density of Sarkes Tarzian's high-current silicon power rectifiers results in longer, more reliable operating life. Compare these key Tarzian values with those of other comparably rated units, and you'll see why Tarzian rectifiers have won such wide acceptance among designers:

DC CURRENT	JUNCTION SIZE	THERMAL GRADIENT (Junction to base)	JUNCTION TEMP. RISE
35 amps	.375 inch	9° Centigrade	60°C Maximum
100 amps	.75 inch	5° Centigrade	60°C Maximum
150 amps	.875 inch	7° Centigrade	60°C Maximum
200 amps	1.0 inch	9° Centigrade	60°C Maximum
*250 amps	1.125 inch	11° Centigrade	60°C Maximum

*Available with stud mounting only

In addition to providing for maximum cooling and larger junction area, Tarzian's unique case styling produces a compact, easily mounted rectifier available in flush or stud mounting types. Tarzian high-current silicon power rectifiers are also available from stock in your choice of negative or positive base polarity.

For complete specifications and ordering information, contact your Sarkes Tarzian sales representative or write to Section 4574 F, Sarkes Tarzian, Inc., Semiconductor Division, Bloomington, Indiana.

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SEMICONDUCTOR DIVISION
BLOOMINGTON, INDIANA
In Canada: 700 Weston Rd., Toronto 9, Ontario
Export: Ad Auriema, Inc., New York City

IRE People

(Continued from page 62A)

James C. Elms (SM'56) has been named to the position of vice president and general manager (defense operations) for the Crosley Division, Avco Corporation. He will have line responsibility over all activities in the Crosley Division relating to military business, and will coordinate and direct the various activities as they relate to individual military programs. Mr. Elms was vice president of ground electronics and communications for the Division prior to his new appointment.

J. C. Elms

Before joining Avco's Crosley Division ten months ago, he was with the Denver Division, Martin Company, as manager of its Avionics Department where he was responsible for the development of guidance and control, electronic, electrical and ordnance equipment for the Titan ICBM. Before joining Martin, he was manager of the fire control engineering department, Autonetics Division, of North American Aviation, Inc., Downey, Calif.

During World War II, he served as an officer in the United States Army Air Force and was assigned to the Air Service Command and then to the Armament Laboratory at Wright Field, Dayton, Ohio.

Mr. Elms is a native of East Orange, N. J. and Phoenix, Ariz. He holds the B.S. degree in physics from the California Institute of Technology and the M.A. degree in physics from the University of California at Los Angeles. He also served as Research Associate at UCLA in the field of geophysics. He holds memberships in the American Rocket Society (ARS), and the Institute of Aeronautical Sciences (IAS).

⁂

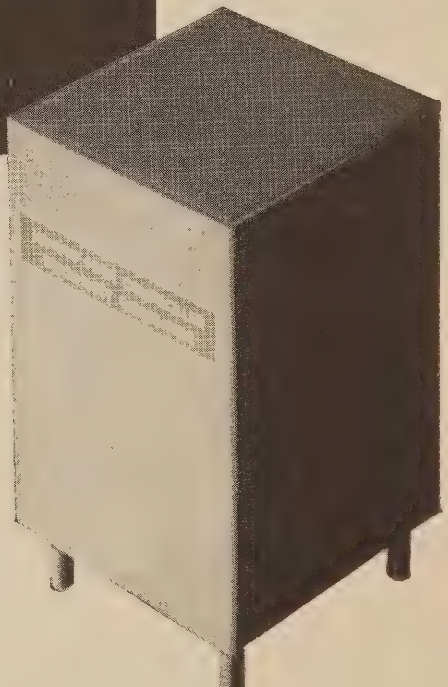
The promotion of **William Glass** (A'54) to Manager of the Dayton, Ohio District Office, has been announced by the Ampex Data Products Company, Redwood City, California. A division of Ampex Corporation, the company manufacturers magnetic tape recorders widely used for the acquisition, storage and processing of business and scientific data. The equipment plays a major part in aircraft and missile testing. In assuming his new position, he will supervise technical sales and customer relations for the area.

W. Glass

Before joining Ampex, he was with the Applied Science Corporation of Princeton (ASCOP). Earlier he did telemetry systems work for RCA's Patrick Air Force Base, Florida installation, and was a re-

(Continued on page 66A)

TUNING FORK CONTROLLED PRECISION FREQUENCY PACKAGES



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Overall accuracies from ±.05% to ±.01% over −55°C to +85°C range, and to ±.001% from zero °C to +75°C, **without** use of ovens.

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Conservatively designed **reliable** units, potted in silicone rubber and hermetically sealed, for operation under **MIL** environmental conditions.

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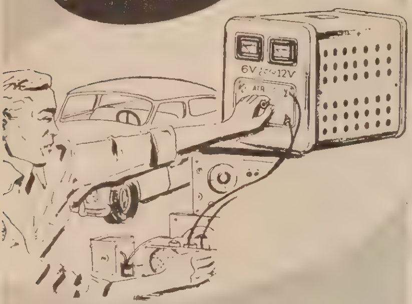

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TRANSISTOR OR VIBRATOR OPERATED
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New Models . . . Designed for testing D.C. Electrical Apparatus on Regular A.C. Lines. Equipped with Full-Wave Dry Disc Type — Rectifier, Assuring Noiseless, Interference-Free Operation and Extreme Long Life and Reliability.

TYPE	INPUT A.C. Volts 60 Cycles	D.C. OUTPUT VOLTS	AMPERES Cont.	Int.	SHIP. WT.	USER PRICE
610C-ELIF	110	6 -or- 12	10 6	20 12	22	$49.95
620C-ELIT	110	6 -or- 12	20 10	40 20	33	$66.95

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Quality Products Since 1931
SAINT PAUL 1, MINNESOTA, U. S. A.

IRE People

(Continued from page 64A)

search and development engineer for Hughes Aircraft, Culver City, California.

Mr. Glass attended the University of Illinois, and is active in the IRE's Committee on Telemetry and Remote Control.

❖

Dr. Charles K. Hager (M'55) has been named section manager of Automatic Controls for Temco Electronics, a division of Temco Aircraft Corporation.

C. K. Hager

Dr. Hager received the B.S., M.S. and Ph.D. degrees from the University of Texas. Prior to joining Temco in June, 1959, he was director of applications research at Varo Manufacturing and previously had been employed at Convair and Mandrel Industries. Before his promotion to section manager responsible for design and development of automatic controls and control systems, he was a scientist in Temco's development and analysis group.

❖

General Electric's Communication Products Department here has named **Elmer W. Hassel** (M'49) as manager of Tone-Signalling and Filter Design Engineering.

E. W. Hassel

The position, newly-created, involves responsibility for design of terminal communication equipment, quartz crystals and filters for General Electric's two-way radio, microwave and carrier current products.

With G-E since 1951, he has specialized in the design and development of selective calling communication devices and tone signalling equipment. He has an extensive background in the field of radio communications, telephone and telegraphy.

Following his graduation from Milwaukee School of Engineering in 1943 with the B.S. degree in electrical engineering, he joined the staff of the Office of the Chief Signal Officer, Wire Communications Section, Engineering and Technical Service, Washington. There, he was engaged in studies related to the development and testing of carrier telephone terminals and repeaters, voice frequency telegraph terminals and repeaters, speech-plus-duplex equipment and amplifiers for the military service.

From 1946 to 1951, he was a faculty member of the Milwaukee School of Engineering where, immediately prior to his association with General Electric Company, he was professor of electrical engi-

(Continued on page 69A)

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Hermetic Seal Corp. Glass-to-Metal and Ceramic-to-Metal Seals for EVERY Electronic Use!

- Crystal Bases
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- Multiple Headers
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A SENSITIVE RESEARCH

TRIPLE PLAY!

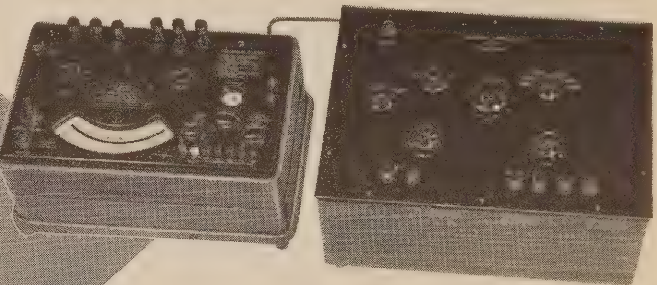
1. AC-DC WIDE RANGE CALIBRATOR

SRIC's versatile AC/DC Volt-Amp-Milliammeter "Self Checking" Model Thach is now offered in combination with a general purpose power supply for use as a convenient, economically priced, wide range instrument calibrator. The Model Thach has 19 overlapping full scale ranges of current and voltage. Operation is almost always at or near full scale for maximum accuracy. The power supply (Model Thach-PS) is a regulated source with its controls interlocked with the Model Thach. Power to the Thach is automatically shut off when ranges are switched, reducing the danger of accidently overloading the calibrator and/or the instrument under test. Output covers the full range of the Thach for DC and 60 cps. 50-2500 cps. can be plugged in for operation over a broader frequency range. Resolution of the power supply controls is better than .05% for any current and voltage range.

Any Model Thach with range combs. 1x or 3x is available for operation with the power supply. In addition, existing instruments in the field can be modernized for this same purpose at a small surcharge.

2. AC-DC LABORATORY STANDARD

The Model Thach can be used independently as a true RMS measuring instrument powered by any appropriate source. It checks its own accuracy against an internal standard cell, and is furnished completely self contained with a high sensitivity galvanometer. General specifications are as follows: Accuracy ± .2% F.S. (.1% at self-check points). Ranges 10/20/50/100/200/500 ma; 1/2/5 amps; 1/2/5/10/20/50/100/200/500/1000 v. Frequency range DC and 7 cps. to 4 kc. Sensitivity 100 ohms/volt. Thermocouple D'Arsonval type. 100 division 6.3" hand drawn mirrored scale. Temperature compensated from 20°C. — 30°C. 1000% manually operated overload protection system. Independent of influence of stray magnetic fields. Diamond Pivoted with sapphire shock mounted jewels. Furnished with 1 or 2 thermocouples. Available in two combinations: 1x is self checking at full scale only; 3x is self checking at 5 cardinal points including full scale. Size 16⅜" x 10½" x 8¾" deep. Weight approx. 21 lbs.



Model THACH AND THACH-PS

3. AC-DC GENERAL PURPOSE POWER SUPPLY

The Model Thach-PS, while designed primarily for operation with the Model Thach, can be used independently as a power source for any appropriate application. It only has to be disconnected from the Model Thach to become an excellent general purpose switch controlled laboratory supply.

SPECIFICATIONS:

OUTPUT: DC or AC (60 cps normal; 50-2500 cps depending on input) **Voltage:** Delivers 0-120% at full load and a max. of 0-175% at no load. 1/2/5 v. at 300 ma.; 10/20/50 v. at 100 ma.; 100/200/500/1000 v. at 25 ma. **Current:** 0-5 amps. at 15 watts max. on low power, or 75 watts max. on high power.

INPUT: 90-135 v., 60 cps single phase, or 115 v. 50-2500 cps from a regulated source.

WAVEFORM: 60 cps distortion 2.5% total harmonic content plus line distortion.

RIPPLE: Varies from .5% at full voltage and low currents to a maximum of 2.5% for currents of 1 ampere or less. At currents above 1 ampere, ripple can always be 3% or less if series resistance is sufficient in external circuit and will be no worse than 7% for any possible operation.

RESOLUTION: .05% or better by means of coarse, medium and fine controls.

SIZE: 12¾" x 17" x 9" deep.

WEIGHT: Approx. 59 lbs.

S
Symbol of Quality

SENSITIVE RESEARCH INSTRUMENT CORPORATION

NEW ROCHELLE, N. Y.

ELECTRICAL INSTRUMENTS OF PRECISION SINCE 1927

THE
X-15:
ACT
ONE
FOR
MAN
IN
SPACE

As North American's X-15 – world's most advanced manned research craft–parts the curtain of earth's atmosphere, the arts of guidance and direction must play a critical role. Sperry's Air Armament Division, assigned the Flight Data System responsibility for the X-15, is meeting the challenge with inertial guidance gear of advanced design, precision and dependability.

But the problems of inertial guidance are not new to Sperry. During the past ten years, over 25-million Sperry man-hours have been employed to develop and produce successful inertial guidance. As a result, the nation has in the Convair B-58 Hustler the most thoroughly studied, analyzed, tested, evaluated and understood inertial guidance system in being – plus the advanced guidance equipment for the X-15 and for other future applications.

And in addition to work on government sponsored space guidance systems and techniques, Sperry scientists and engineers are exploring new and exotic techniques for gyros, advanced miniaturized digital computers, acceleration sensors, zero gravity environment systems–in many cases involving radical departures from current technology–with the aim of developing concepts, systems and hardware that are *ahead* of the challenges of man in space.

SPERRY

AIR ARMAMENT DIVISION, *SPERRY GYROSCOPE COMPANY, DIVISION OF SPERRY RAND CORPORATION, GREAT NECK, NEW YORK*

(Continued from page 66A)

neering and head of the electronics branch of the department of electrical engineering.

Mr. Hassel is a member of the American Institute of Electrical Engineers. He is also affiliated with the Lynchburg Society of Engineering and Science.

❖

Frank J. Hierholzer, Jr. (M'58) has been named Assistant Department Head of the Microtronics Department of Sperry Semiconductor, South Norwalk, Conn.

F. J. Hierholzer, Jr.

He brings to Sperry extensive experience in semiconductors. He was Senior Engineer in the Solid State Electronics Engineering Section of the Materials Engineering Department of Westinghouse Electric Corp. He received the B.S. degree in Electrical Engineering, with honors, at Virginia Polytechnic Institute, the M.S. degree at Stevens Institute of Technology, and is completing the Ph.D. requirements at the University of Pittsburgh.

An associate member of American Institute of Electrical Engineers, Mr. Hierholzer has presented a technical paper to AIEE on "Linear Power Amplifier Using Dynistors or Trinistors." He has several patents in the fields of arc discharge devices and semiconductor applications.

❖

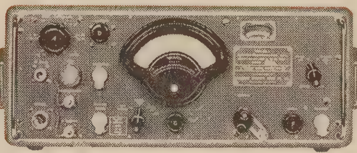
Watkins-Johnson Co. has announced additions to its technical staff engaged in research and development on microwave tubes and devices.

Dr. Boyd P. Israelsen (S'53–A'54–S'58), whose attention will be directed toward the development of low-noise traveling wave tubes, was a National Science Foundation Fellow and research assistant at Stanford Electronics Laboratories. Before coming to Stanford, where he was awarded his Ph.D., Dr. Israelsen was a senior research engineer at Jet Propulsion Laboratory, Pasadena, working on components for missile guidance systems. He has the B.S. and M.S. degrees from California Institute of Technology.

Dr. Kenneth L. Kotzebue (S'56–M'59), who will work on solid-state and electron beam parametric amplifiers, was formerly a senior engineer with the Apparatus Division of Texas Instruments, Inc., Dallas. He has made significant contributions in the field of parametric amplifiers. He was a Bell Telephone Laboratories Fellow at Stanford University, where he received his Ph.D. last year, and a research assistant at Stanford Electronics Laboratories. His B.S. degree is from the University of Texas and his M.S. degree is from the University of California at Los Angeles.

❖

(Continued on page 70A)



NEW

RADIO INTERFERENCE — FIELD INTENSITY MEASURING EQUIPMENT, 375 mc to 1000 mc

The NEW NM-52A RI-FI instrument developed by STODDART to government specifications is now ready for immediate delivery.

Its purpose is to investigate, analyze, monitor and measure to the highest practical degree conducted or radiated electromagnetic energy to military specifications within the frequency range of 375 mc to 1000 mc. In addition, the NM-52A is valuable as a highly sensitive frequency-selective voltmeter and receiver for numerous laboratory and field applications.

OUTSTANDING FEATURES

SENSITIVITY OF 1 MICROVOLT ACROSS 50 OHMS, provides up to 40 db more than Military Measurement Requirements.
SINGLE KNOB TUNING.
RAINPROOF, DUSTPROOF, RUGGEDIZED AND TOTALLY ENCLOSED, for all-weather field use or precise laboratory measurements.
NEW BROADBAND ANTENNA, for rapid detection and measurement of radiated energy over entire frequency range.
NEW POWER SUPPLY, 0.5% REGULATION, for filament, bias and plate voltages, and also for use as a standard laboratory power supply.
OSCILLATOR RADIATION LESS THAN 20 MICRO-MICROWATTS, over 20 times better than Mil-Specs require.
TWO DECADE LOGARITHMIC METER SCALE, increases range of voltage measurement without change of attenuator steps.
THREE DETECTOR FUNCTIONS, for peak, quasi-peak or average measurements.
PORTABLE OR RACK MOUNTING, no modification required for laboratory, mobile, airborne or marine installation.
I-F OUTPUT FOR PANORAMIC DISPLAY OR NARROW BAND AMPLIFICATION, for visual presentation or increased sensitivity.
OVER 100 DB SHIELDING EFFECTIVENESS, increases measurement capabilities in presence of strong fields.
VISUAL PEAK THRESHOLD INDICATOR, for accurate slide-back peak voltage measurements.
CONSTANT BANDWIDTH OVER ENTIRE FREQUENCY RANGE.

The NM-52A now joins the family of STODDART government approved RI-FI instrumentation covering the frequency range of 30 cps to to 10.7 kmc to provide the finest RI-FI measuring equipment.

Basic Design + Good Instrumentation = Electronic Compatibility

serving 33 countries in Radio Interference control

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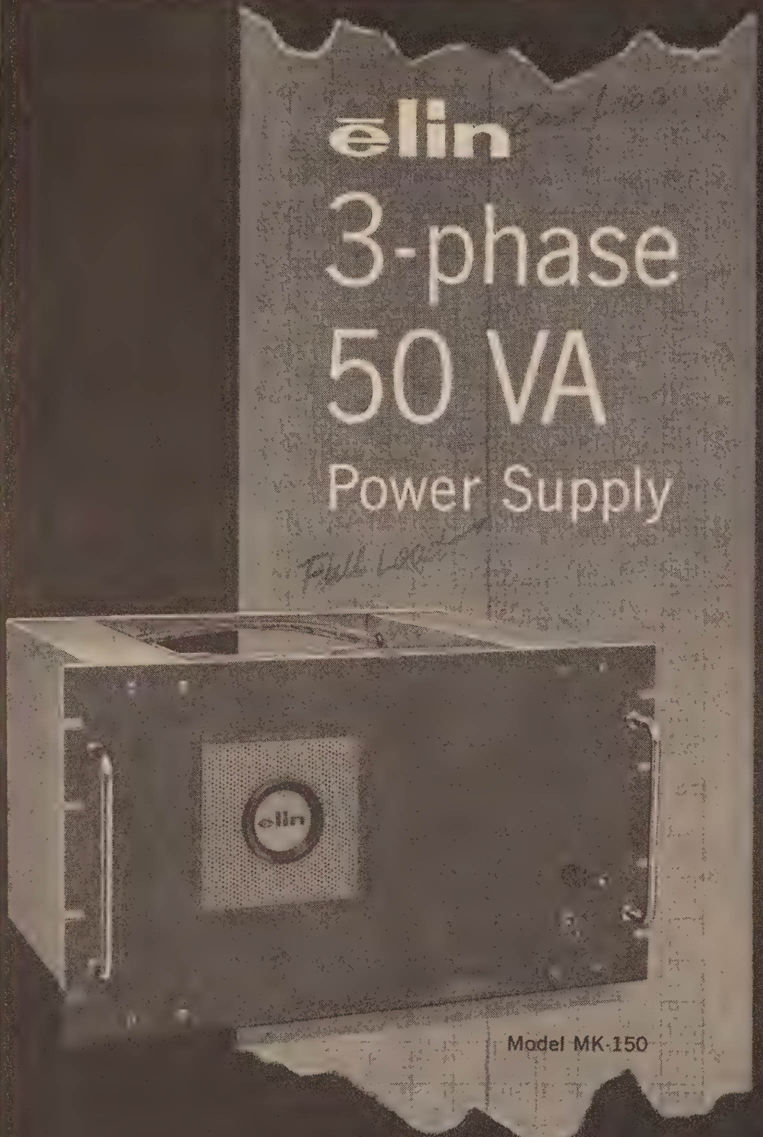

Ultra-stable, fine line characteristics — the kind you need and can depend on, are in ELIN's latest 3-phase 50 VA Power Source! Voltage and current sensing on each leg provide super-regulated output. Delta and Wye connections are at rear panel. Input Voltage, 105-125V, single phase. Input Power 225W. Output Voltage ±0.1%. Output Frequency ±0.1%. Output Regulation 0.1% Line to Line. Output Distortion 0.2%. Load Power Factor up to 0.3 inductive. Write for ELIN Technical Data—today!

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IRE People

(Continued from page 69A)

Formation of an Antenna and Microwave Component Development Group at Granger Associates here has been announced by Dr. John V. N. Granger, president.

Centralized in the new section will be the firm's activities in the development and manufacture of large parabolic reflector antennas, wide-band log periodic antennas, antennas for missiles and aircraft and associated devices such as multiplexers and band-separation filters.

Dr. Granger said recent additions to the engineering staff in this technical area, together with new development and fabrication facilities recently added, will increase his firm's emphasis on antenna systems and associated components and allow the initiation of new programs in steerable arrays, direction-finding systems and microwave circuitry.

Joining Granger in December to head the new group was **Dr. Ray Justice** (A'55–SM'58), formerly supervisor of research and development on the Radiation Research and Development Section at Convair Division of General Dynamics, San Diego, Calif.

At Convair he directed design and development work in the radomes, antennas, microwaves, solid-state electronics and infra-red and optics groups.

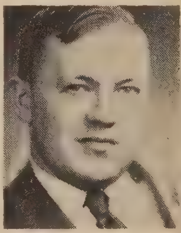
From 1944 until joining Convair in 1956, he was at Ohio State University. There he served at various times as an instructor in the Departments of Mathematics and Electrical Engineering. Primarily he was a research associate at the Antenna Laboratory of the Ohio State University Research Foundation, conducting basic studies in the fields of microwave antennas, arrays and electromagnetic scattering.

Dr. Justice is a member of Sigma Xi and Eta Kappa Nu. He is active in the IRE Professional Groups for Antenna and Propagation and Microwave Theory and Techniques. He is the author of various Ohio State University reports and PGAP papers on near-field measurements.

❖

Jack Larsen (M'48–SM'53) has been named Manager of the Special Projects Department by John F. Brinster, President of General Devices, Inc., of Princeton, N. J.

He is a graduate of Princeton University, the University of Michigan, and George Washington University, with degrees in physics, mathematics, and law. He is a member of the District of Columbia Bar and a registered Patent Attorney.



J. Larsen

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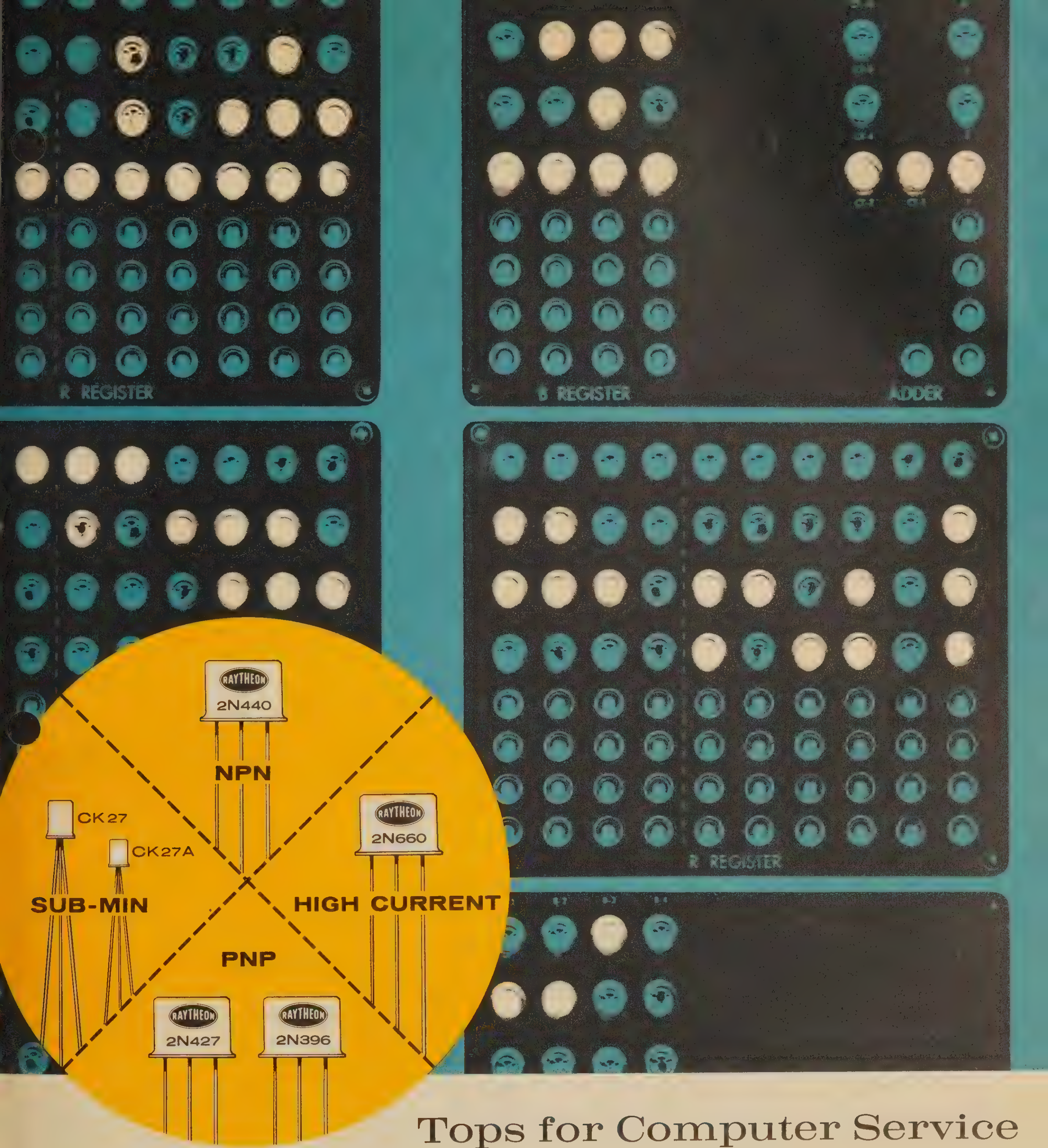
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B REGISTER
ADDER
R REGISTER
RAYTHEON
2N440
NPN
CK27
CK27A
SUB-MIN
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HIGH CURRENT
PNP
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Tops for Computer Service

These Raytheon germanium transistors are top choices of computer engineers for a number of important reasons. They were developed with computer applications specifically in mind — voltage, gain, and response characteristics are optimized for this type of service. In medium frequency computer applications, these Raytheon switching transistors give you the reliability derived from years of production experience. And Raytheon's quality control program assures strict product uniformity and rigid adherence to specifications.

Result of all this is an extensive line of computer transistors that have set highest industry standards for quality and reliability. With the 2N396, which provides an internal base to case connection, Raytheon now gives you an important addition to a broad line of PNP, NPN, subminiature, and high current switching transistors. More details are given on the other side of this page.

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WITH
TRADITIONAL
RAYTHEON
RELIABILITY

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FOR GENERAL APPLICATION . . . THE 2N396 SERIES PNP germanium strapped base transistors for general switching service. Temperature range −65°C. to +100°C. Immediate availability.

Type	B_{VPT} Max. Volts	f α b mc	H_{FE1}	H_{FE2}	R_{sat} ohms
2N395	15	4.5	40	12	2.2
2N396	20	8.0	60	20	1.3
2N397	15	12.0	80	35	1.1

A COMPLETE HIGH CURRENT SWITCHING LINE PNP germanium switches for 1 amp, high frequency, high gain service. Temperature range −65°C. to + 85°C. Long a production item — excellent availability in large volume.

Type	B_{VPT} Max. Volts	f α b ave. mc	H_{FE1} ave. $I_B = 1$mA $V_{CB} = -0.25$V	H_{FE2} ave. $I_B = 10$mA $V_{CE} = -0.35$V	$I_C = 150$mA ohms
2N658	−16	5	50	40	0.9
2N659	−14	10	70	55	0.6
2N660	−11	15	90	65	0.45
2N661	− 9	20	120	75	0.35
2N662	−11	8	30 min.	50	0.7

IMPROVED DISSIPATION AT LOWER CURRENT VALUES NPN germanium transistors for medium current, high frequency, high gain switching service. Temperature range −65°C. to +85°C. Immediate availability.

Type	B_{VPT} Max. Volts	f α b mc	H_{FE1}	R_{sat} ohms
2N438	25	2.5	25	3.0
2N439	20	5.0	45	3.0
2N440	15	10.0	70	3.0

HIGH RELIABILITY PNP TRANSISTORS germanium transistors for medium current, high frequency switching service. Temperature range −65°C. to +85°C. Immediate availability.

Type	B_{VPT} Max. Volts	f α b mc	H_{FE1}	H_{FE2}	R_{sat} ohms
2N425*	−30	4	30	15	2.2
2N426*	−25	6	40	18	2.2
2N427*	−20	11	55	20	1.3
2N428*	−15	17	80	30	1.1
2N404*	−24	12	See Data Sheet		

* Available to MIL Specification

SUB-MINIATURE TRANSISTORS Sub-miniature transistors for medium current, high frequency, high gain switching. Temperature range −65°C. to +85°C. Immediate availability.

TYPE .130″ Dia. x .160″ High	TYPE .100″ Dia. x .130″ High	B_{VPT} Max. Volts	f α b mc	H_{FE1}	H_{FE2}	R_{sat} ohms
CK 25	CK 25A	−30	4	30	15	2.2
CK 26	CK 26A	−25	6	40	18	2.2
CK 27	CK 27A	−20	11	55	20	1.2
CK 29	CK 28A	−15	17	80	30	1.1

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(Continued from page 70A)

Together with Mr. Brinster, he was one of the organizers of early research in radio telemetering at Princeton University. With the University of Michigan, and later with the Martin Company and the Navy Department, he continued in the general field of missile electronics and control, working on such projects as Matador, Mace, Bomarc, Terrior, Jupiter and Polaris. He served as consultant to the Atomic Energy Commission in the development of electronic portions of reactor controls for the submarines, Nautilus and Sea Wolf. He headed the Navy Department's Missile Guidance Section on the Polaris Project and was honored with the Meritorious Civilian Service Award for his contributions to the Navy Department. Immediately before coming to General Devices, he was a member of the Patent Department of the Bell Telephone Labs.

A member of the New Jersey Patent Law Association and the Acoustical and Physical Societies, Mr. Larsen holds a number of patents in the electronics field.

❖

The appointment of **Paul J. Larsen** (A'37–M'41–SM'43) as director of government relations for Allen B. Du Mont Laboratories, Inc. has been announced by Dr. Allen B. Du Mont, the company's chairman. Mr. Larsen will maintain liaison for Du Mont Laboratories with both civilian and military branches of the government for its military electronic systems and for its commercial electronic products. He will make his offices at Du Mont's Washington, D. C. headquarters, in the Pennsylvania building.

P. J. Larsen

Formerly director of Civil Mobilization and Defense, Executive Office of the President of the United States, he is a veteran of more than 30 years experience in the electronics industry. He comes to Du Mont from Hughes Aircraft Company, where he was manager of East Coast Operations and assistant secretary stationed in Washington. Prior business and professional background include his association with Borg-Warner Corp. as assistant to the president responsible for all governmental defense activities. Before that he was associate director of Los Alamos Scientific Laboratory, and next the director of Sandia Laboratory, and consultant to the President on activities of the newly formed Sandia Corporation.

He was also associated with Johns Hopkins University from 1941–47 and had charge of engineering and production throughout the United States on radio proximity fuses. Prior associations were with Baird Television Corp. of England,

(Continued on page 74A)

NEW!...

CONVERTS AC to DC LINEARLY

from 1 mv to 1000 v

Accuracy of conversion
is BETTER THAN 0.25%
for frequencies 50 cps to 10 KC

Price $450

BALLANTINE'S LINEAR AC to DC CONVERTER
Model 710

The Model 710 Linear AC to DC Converter converts an AC voltage to a DC voltage which can be measured with an accurate DC device such as Type K Potentiometer, Digital DC Voltmeter, Recorder, etc. With such a combination, a wide range of voltages can be measured with up to 0.25% accuracy, which is considerably better than accuracies of present-day vacuum tube voltmeters. Such a system is more sensitive, covers a wider frequency and voltage range, and is much more rugged and foolproof than a laboratory standard instrument of comparable accuracy. It is also adaptable for use by untrained personnel and on production lines.

The instrument covers an input voltage range of 1 mv to 1000 volts which is divided into six decade ranges. For every decade range the DC output varies from 0.1 volt to 1 volt. The input impedance of the converter has a resistive component of 2 megohms shunted by 15 pf to 25 pf, depending on the range.

The output of the Model 710 Converter is a linear function of the input voltage within each decade. A small error may exist in the decading of the input attenuator or in the frequency response of the amplifier. This error does not exceed ±0.25% over a frequency range of 50 cps to 10 KC and ±0.5% over a range of 30 cps to 50 KC. The upper frequency limit of the instrument is 250 KC, at which point the accuracy is ±1%.

The DC output of the converter is single ended and has a maximum output emf of 1 volt with a source impedance of approximately 10,000 ohms. The instrument is the average responding type for distortions as much as 30%, but is calibrated in RMS of a sinewave.

Also available in 19 inch relay rack as Model 710 S/2 Price $455

Write for brochure giving many more details

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CHECK WITH BALLANTINE FIRST FOR LABORATORY AC VACUUM TUBE VOLTMETERS, REGARDLESS OF YOUR REQUIREMENTS FOR AMPLITUDE, FREQUENCY, OR WAVEFORM. WE HAVE A LARGE LINE, WITH ADDITIONS EACH YEAR. ALSO AC DC AND DC/AC INVERTERS, CALIBRATORS, CALIBRATED WIDE BAND AF AMPLIFIER, DIRECT-READING CAPACITANCE METER, OTHER ACCESSORIES.

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IRE People

(Continued from page 73A)

Warner Bros. Pictures, and Marconi Wireless Telegraph Co.

He is a recipient of the Presidential Certificate of Merit and Citation and has served on the Technical Advisory Panel on Aeronautics and the Panel on Nucleonics.

A fellow of the Society of Motion Picture and Television Engineers, Mr. Larsen is a member of numerous other professional organizations connected with aviation, missiles, ordnance, and engineering.

❖

Albert V. J. Martin (SM'56) has left the United States to return to his native country, France. For 3 years he was assistant Professor of Electrical Engineering at Carnegie Institute of Technology, Pittsburgh, Pa.

A. V. J. MARTIN

Dr. Martin has set up a publishing company at 61, rue de Maubeuge, Paris, 9, France. Its first product is a technical magazine entitled "Electronique et Automatisme," the first issue of which appeared in January, 1960.

Dr. Martin is a member of the American Institute of Electrical Engineers, the British Institution of Radio Engineers, Sigma Xi, and Société Française des Radioélectriciens.

❖

Dr. Maurice Nelles (M'59) has joined American Electronics, Inc., Los Angeles, Calif., to fill the newly-created post of Vice President Engineering, according to Phillip W. Zonne, President of the firm. In this new position, Dr. Nelles will direct the engineering planning for the corporation and its nine divisions on both this coast and the Atlantic seaboard.

M. NELLES

Immediately prior to joining American Electronics, Inc., he was Vice President Research and Development and Chairman of the Corporate Product Planning Committee of Crane Company, Chicago. He was also a Director of the Hydro-Aire Company division of Crane, as well as a Director of Crane, Ltd., which operated seven plants in Canada and one in England.

Before his association with the Crane Company, he was Director of Research for Borg-Warner Corporation, and Director of diversification and research development for Technicolor Corporation. He has also served as Professor and Head of the Aeronautical Engineering Department, University of Southern California, Manager of

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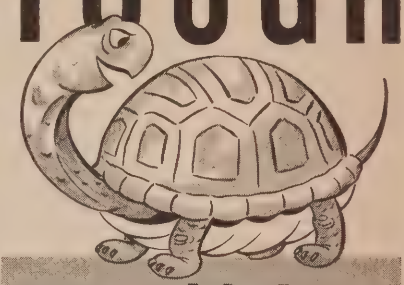
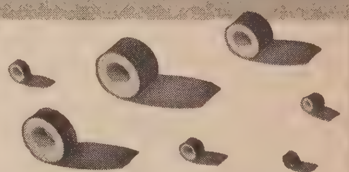
TOUGH



...AS A
TURTLE'S BACK



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BOBBIN CORES
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Tough-as-tortoise-shell Armag armor is an exclusive Dynacor development. It is a thin, non-metallic laminated jacket for bobbin cores that replaces the defects of nylon materials and polyester tape *with very definite advantages* —and, you pay no premium for Armag extra protection.

Tough Armag is suitable for use with normal encapsulation techniques on both ceramic and stainless steel bobbins. It withstands 180°C without deterioration—is completely compatible with poured potted compounds—has no abrasive effect on copper wire during winding—fabricates easily to close-tolerance dimensions—inner layer is compressible to assure tight fit on bobbin—does not shrink, age or discolor.

Write for Engineering Bulletins DN 1500, DN 1000A, DN 1003 for complete performance and specification data covering the wide range of Dynacor low cost Standard, Special and Custom Bobbin Cores—all available with Armag non-metallic armor.

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SILECTRON CORES
Types C, E and O

BOBBIN CORES
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The ARNOLD LINE-UP includes ANY TAPE CORES you need

APPLICATIONS

We'll welcome your inquiries on your Tape Wound Core requirements for Pulse and Power Transformers, 3-Phase Transformers, Magnetic Amplifiers, Current Transformers, Wide-Band Transformers, Non-Linear Retard Coils, Reactors, Coincident Current Matrix Systems, Static Magnetic Memory Elements, Harmonic Generators, etc.

ENGINEERING DATA

For data on the various types of Arnold Tape Cores, write for these Bulletins:

SC-107A—Silectron Cores, Types C, E and O
TC-101A—Toroidal Cores, of Supermalloy, Deltamax and 4-79 Mo-Permalloy
TC-108A—Bobbin Cores
TC-113A—Supermendur Tape Cores

ADDRESS DEPT. P-4

Arnold produces Silectron C, E and O cores, aluminum and plastic cased toroidal cores of high-permeability materials, and bobbin-wound cores to meet whatever your designs may require in tape thickness, material, core size or weight.

As a fully integrated producer, Arnold controls every manufacturing step from the raw material to the finished core . . . and modern testing equipment permits 100% inspection of cores before shipment.

Wide selections of cores are carried in stock as standard items for quick delivery; both for engineering prototypes to reduce the need for special designs, and for production-quantity shipments to meet your immediate requirements.

• *Let us help you solve your tape core problems.* Check Arnold, too, for your needs in Mo-Permalloy or iron powder cores, and for cast or sintered permanent magnets made from Alnico or other materials. Just write or call *The Arnold Engineering Company, Main Offices, Marengo, Illinois.*

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WESGO knows full well the need for quality in even so relatively a minor item as brazing alloys in vacuum tube construction and will, therefore, not compromise with this factor for the sake of cost. This high quality is maintained in the conventional alloys as well as a series of new brazing alloys developed by WESGO specifically for vacuum systems use. Brochure with full descriptions of standard WESGO Low Vapor Pressure Brazing Alloys is available upon request.

★

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(Continued from page 74A)

Research, Allan Hancock Foundation, and Professor and Director of the Engineering Experiment Station at Pennsylvania State University.

During World War II, he was Deputy Director of the War Production Board, and Chief Engineer, Office of Production Research and Development. He is a member of American Society of Mechanical Engineers, American Society of Tool Engineers, Institute of Aeronautical Sciences, Society of Automotive Engineers, American Rocket Society, America Society of Metals, American Institute of Naval Engineers, American Institute of Mining, Metallurgical and Petroleum Engineers, and Trustee of the Midwest Research Institute.

Dr. Nelles received the B.A. and M.A. degrees from the University of South Dakota, and a Ph.D. degree from Harvard University.

⁂

G. Emerson Pray (M'41–SM'53) has been elected a vice president of Ling-Altec Electronics, Inc. to direct the company's activities related to the national defense program, it was announced today by James J. Ling, chairman of the board.

G. E. Pray

He will operate from the Washington, D. C. office to facilitate the company's negotiations of prime and subcontracts for its 14 operating subsidiaries and divisions engaged in governmental work.

A licensed professional engineer and physicist with a background of scientific work and experience in company management, Mr. Pray recently resigned as assistant to the president and director of government operations of Dresser Industries, Inc.

He holds an electrical engineering degree from Rensselaer Polytechnic Institute and the M.S. degree in physics from Rutgers University. He has patented many of his inventions in the radio, electronic and sonic fields, and is a well-known authority and lecturer in these areas of scientific research and development.

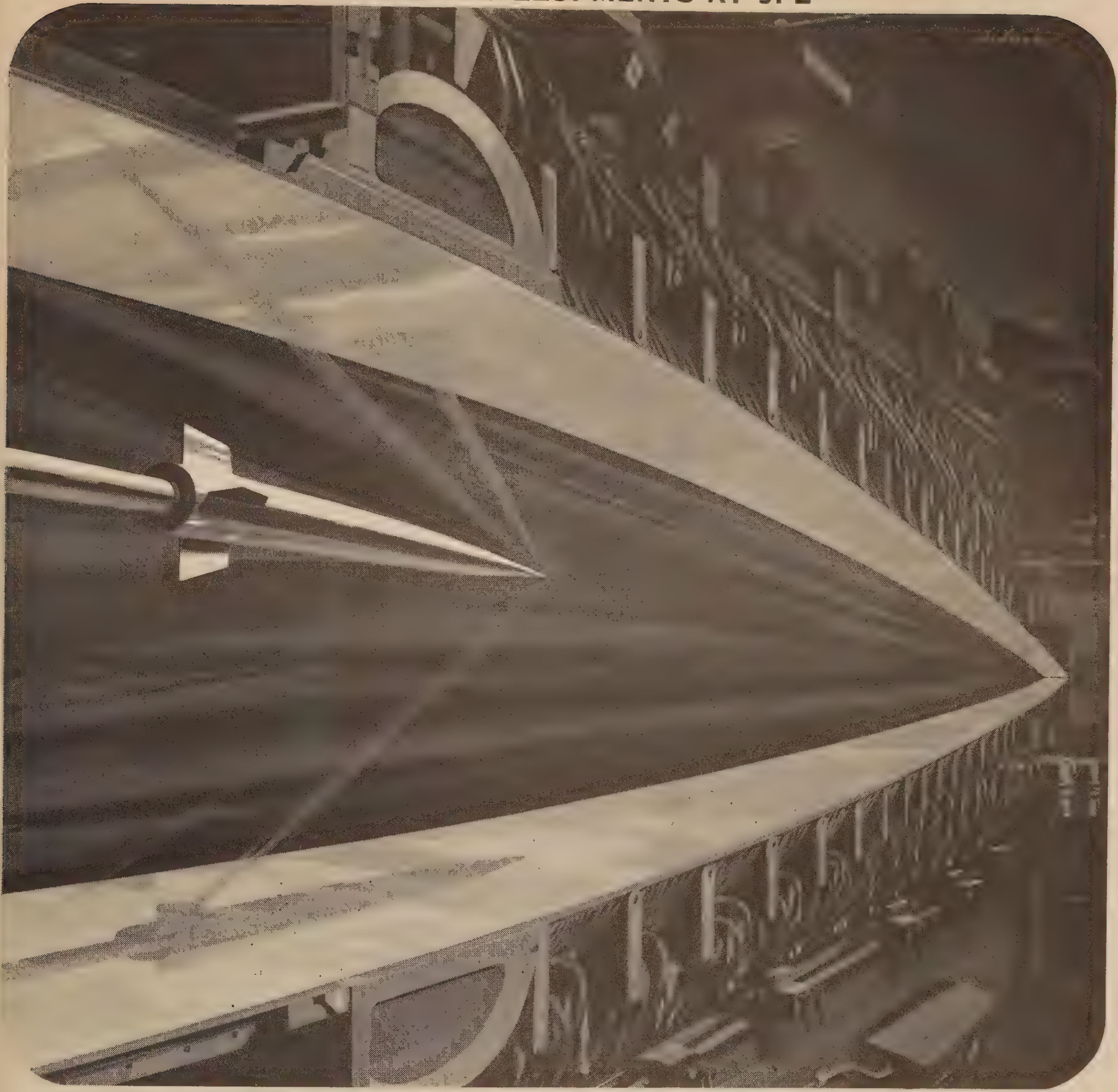
⁂

Dr. James A. Van Allen (SM'59–F'60), discoverer of the radiation belts surrounding the earth which bear his name, has been named by the Institute of the Aeronautical Sciences to receive the second annual Louis W. Hill Space Transportation Award.

The award was established by the Louis W. and Maud Hill Family Foundation of St. Paul for the purpose of "encouraging and supporting fundamental research and the early application of new knowledge in behalf of the welfare of mankind." One of the top awards in the aerospace field, it includes an honorarium of $5,000. ($10,000 if more than one recipient is named).

(Continued on page 78A)

NOTABLE DEVELOPMENTS AT JPL



HYPERSONIC WIND TUNNEL

One of the latest research facilities at the Jet Propulsion Laboratory is the recently completed, continuous-flow hypersonic wind tunnel. Developed by the Lab, this new tunnel generates air speeds up to ten times the speed of sound. Its 21-inch square test section provides accommodation for models up to four feet long thus permitting increased model instrumentation. This large test section at Mach 10 with a continuous uniform air flow broadens JPL capabilities in the important area of fluid dynamic research.

To minimize structural deflections due to temperature changes and thus the time required to reach equilibrium conditions, the entire tunnel structure is water cooled and housed in an air conditioned building. Any Mach number between five and ten can be precisely set by means of flexible stainless steel nozzle plates that are positioned to a ten-thousandth of an inch. Calibration results indicated satisfactory solution of the design problems encountered.

The high speed data-acquisition, reduction, and presentation system is designed for high production testing of the nation's most advanced missiles and re-entry configurations. Stability and control phenomena in new regimes can be studied experimentally under carefully controlled conditions.

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JET PROPULSION LABORATORY
A Research Facility operated for the National Aeronautics and Space Administration
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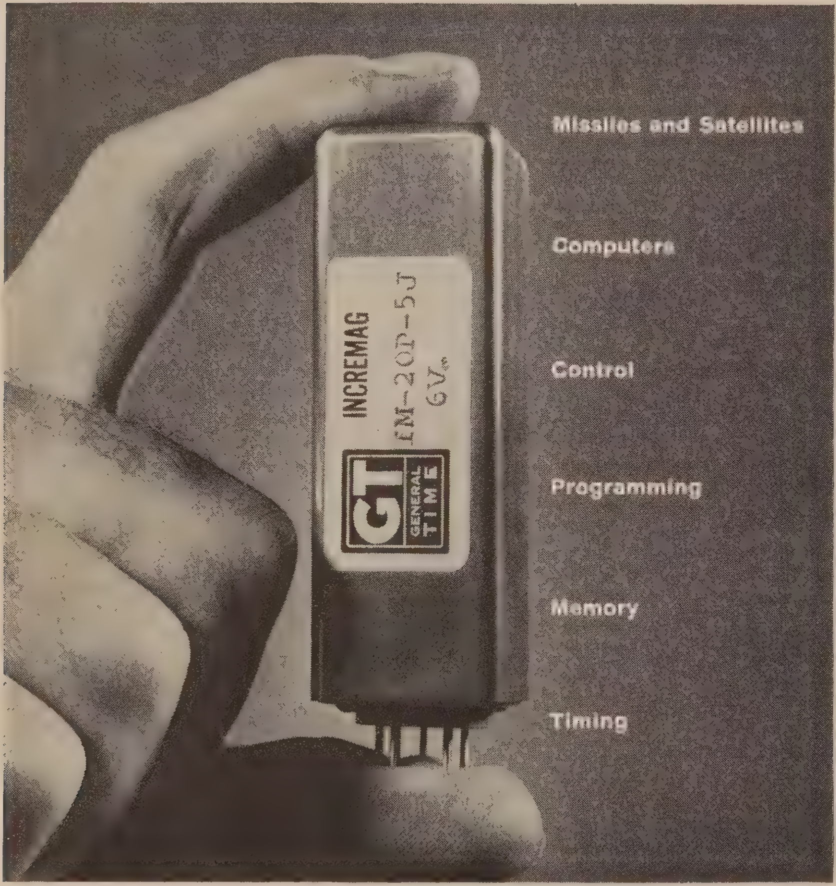

GENERAL SPECIFICATIONS

COUNTING RATE: up to 100,000 pps max.
TEMPERATURE RANGE: −55°C to +125°C
COUNT PER STAGE: up to 16 max. in ½ cubic inch
NUMBER OF STAGES: as required
VOLTAGE TOLERANCE: ±10% most cases

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Electronic Products and Systems

IRE People

(Continued from page 76A)

Dr. Van Allen, who heads the department of Physics and Astronomy at the State University of Iowa, detected the radiation belts on the basis of data obtained by Explorer I. The award citation states "By combining simple and direct techniques with great ingenuity, he established beyond doubt the existence, intensity and extent of the radiation belts above the earth's surface that now carry his name."

Dr. Van Allen will receive the Hill Award at the annual Honors Night Dinner of the Institute of the Aeronautical Sciences which will be held at the Astor Hotel in New York on January 26, 1960. He will be present in person to accept.

❖

Varian Associates has announced the appointment of **Willis H. Yocom** (A'54–M'57) as Manager, Wave Tube Development. He will head research and development of all wave tubes.

W. H. Yocom

He received the B.A. degree in physics from Oberlin College, the B.S. degree in electrical engineering from M.I.T., and the M.S. degree in electrical engineering from Stevens Institute of Technology. From 1942 to 1956 he did research and development work for Bell Telephone Laboratories. He joined Varian Associates' Tube Division in 1956.

Mr. Yocom holds five patents in the microwave tube field including the Basic patents on slalom focusing. He is a member of Sigma Xi.

❖

Homer A. Ray, Jr. (A'45–M'50–SM'55) has been selected for the newly-created position of Engineering Assistant at Rixon Elctronics Inc., according to C. J. Harrison, Vice President and Operations Director. In this capacity, he will assist Mr. Harrison in the engineering phases of planning and production operations.

H. A. Ray, Jr,

Prior to joining ing Rixon, he was Manager of the Engineering Division, Smith Electronics, Inc. There, he assisted in the development, engineering, drawings, and specifications for the Voice of America's proposed new East Coast Facility. Before that he was Chief Engineer and Director of Photogrammetry, Inc., making optical and electronic instruments primarily for the Navy.

With Page Communications Engineers from 1955 to 1956, he was Head of the Antenna Section and Assistant Manager of

(Continued on page 80A)

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Precision Standard Tooling makes the Difference – The HUDSON line provides complete versatility for the designer/engineer. The industry's widest range of round, square and rectangular closures supplied with dozens of modifications to meet unusual applications. Standardized designs assure fast delivery and precision quality – every time! All finishes available on components of mu metal, nickel-silver, aluminum, brass, copper, stainless steel and steel. Call or write for quotations.

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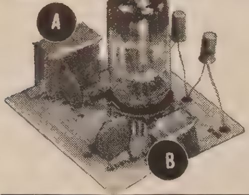


Thin Versatile Co-Netic and Netic Magnetic Shielding Foils

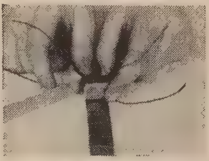
Permit positioning foil-wrapped components A & B closely, minimizing interaction due to magnetic fields . . . making possible compact and less costly systems.

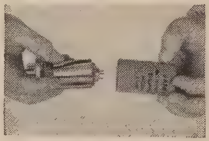
How thin Co-Netic and Netic foils lower your magnetic shielding costs:
1) Weight reduction. Less shielding material is used because foils (a) are only .004″ thick and (b) cut and contour easily.
2) Odd shaped and hard-to-get-at components are readily shielded, saving valuable time, minimizing tooling costs.

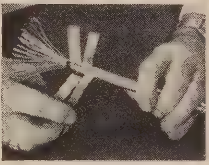
These foils are non-shock sensitive, non-retentive, require no periodic annealing. When grounded, they effectively shield electrostatic and magnetic fields over a wide range of intensities. Both foils available from stock in any desired length in various widths.

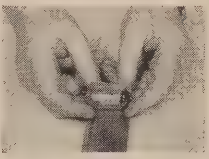
Co-Netic and Netic foils are successfully solving many types of electronic circuitry magnetic shielding problems for commercial, military and laboratory applications. These foils can be your short cut in solving magnetic problems.

Cuts readily to any shape with ordinary scissors.


Wraps easily.


Inserts readily to convert existing non-shielding enclosures.

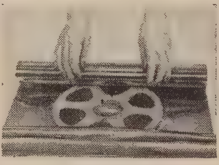

Shielding cables reduces magnetic radiation or pickup.

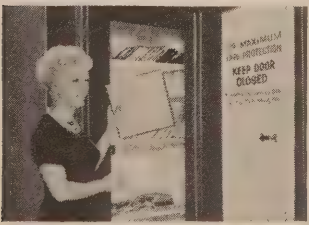

Wrapping tubes prevents outside magnetic interference.

PROTECT VITAL MAGNETIC TAPES

When accidentally exposed to unpredictable magnetic fields, presto!—your valuable data is combined with confusing signals or even erased.

For complete, distortion-free protection of valuable magnetic tapes during transportation or storage. Single or multiple reel Rigid Netic Enclosures available in many convenient sizes and shapes.


Thin pliable foil wraps easily around magnetic tape, maintaining original recorded fidelity.



Rigid Netic (.014″ and up in thickness) Shielded Rooms and Enclosures for safe, distortion-free storage of large quantities of recorded magnetic tapes.

Composite photo to demonstrating that magnetic shielding qualities of Rigid Netic Alloy Material are not significantly affected by vibration, shock (including dropping or bumping) etc. Netic is non-retentive, requires no periodic annealing.

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IRE People

(Continued from page 78A)

the Page Communications phases of the DEW Line Project. He was manager of the engineering and procurement phases of the NATO Project that installed NATO's communications network from Paris through Naples to Izmir, Turkey.

His earlier job experience was with The Queen City Broadcasting Corp. of Seattle, Wash. as Chief Engineer and also as Chief Engineer of the Field Division of Developmental Engineering Corp. doing research and development work on antennas and instruments. Previously, he had a Consulting Engineering Office in Washington, D. C. in partnership with George E. Gautney & Ray, with a practice in broadcast and television engineering.

Mr. Ray was educated at Kent State, Kent, Ohio and the University of Cincinnati and is a Registered Professional Engineer in the District of Columbia. He is associated with Broadcasting Magazine, and is a member of the American Society of Photogrammetry and holds patents in this field.

⁂

Hermon H. Scott (M'35—SM'43—F'52) president of H. H. Scott, Inc., Maynard, Mass., has been elected chairman of the board of directors of the Institute of High Fidelity Manufacturers.

H. H. Scott

The Institute, an association of leading producers of component high fidelity equipment, was formed in 1955 to educate the public about component high fidelity and to set industry standards. Started with 23 members, the Institute membership now numbers more than 120 leading manufacturers, recording companies and publishers throughout the country.

An electrical engineer with B.S. and M.S. degrees from the Massachusetts Institute of Technology, he is a fellow of the Audio Engineering Society and the Acoustical Society of America. He is credited with the design of the first modern-type sound level meters and the first high quality broadcast station monitoring equipment.

Mr. Scott has published numerous technical papers on the measurement and reproduction of sound and related laboratory measuring equipment and holds patents on many developments in these fields. In 1951 he was cited by the Audio Engineering Society for "outstanding achievement in the field of audio engineering."

⁂

Smyth Research Associates, Inc., has named **Louis G. Trolese** (A'30–SM'47–F'60) Vice President for Engineering. This new position reflects the firm's expanded activity in the development of electronic components and systems.

(Continued on page 82A)

A TALENT FOR BINARY DATA LINK SYSTEMS

The application of binary data link transmission to large or small radio networks is made feasible by the Stromberg-Carlson Automatic Binary Data Link.

The broad capabilities of the equipment include:

- 5-character alphabetical address, providing over 11 million private addresses;
- automatic response to interrogation, which provides a 5-character alphanumeric message useful for indicating any element of a status report such as altitude, heading, position.
- Tape readout in the airborne unit.

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INTERELECTRONICS VOLTAGE REGULATED INTERVERTER POWER SUPPLY

Interelectronics all-silicon thyratron-like gating elements and cubic-grain toroidal magnetic components convert DC to any desired number of AC or DC outputs from 1 to 10,000 watts.

Ultra-reliable in operation (over 260,000 logged hours), no moving parts, unharmed by shorting output or reversing input polarity. Wide input range (18 to 32 volts DC), high conversion efficiency (to 92%, including voltage regulation by Interelectronics patented reflex high-efficiency magnetic amplifier circuitry).

Light weight (to 6 watts/oz.), compact (to 8 watts/cu. in.), low ripple (to 0.01 mv. p-p), excellent voltage regulation (to 0.1%), precise frequency control (to 0.2% with Interelectronics extreme environment magnetostrictive standards or to 0.0001% with fork or piezoelectric standards).

Complies with MIL specs. for shock (100G 11 mlsc.), acceleration (100G 15 min.), vibration (100G 5 to 5,000 cps.), temperature (to 150 degrees C), RF noise (I-26600).

AC single and polyphase units supply sine waveform output (to 2% harmonics), will deliver up to ten times rated line current into a short circuit or actuate MIL type magnetic circuit breakers or fuses, will start gyros and motors with starting current surges up to ten times normal operating line current.

Now in use in major missiles, powering telemeter transmitters, radar beacons, electronic equipment. Single and polyphase units now power airborne and marine missile gyros, synchros, servos, magnetic amplifiers.

Interelectronics—first and most experienced in the solid-state power supply field produces its own all-silicon solid-state gating elements, all high flux density magnetic components, high temperature ultra-reliable film capacitors and components, has complete facilities and know how —has designed and delivered more working KVA than any other firm!

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IRE People

(Continued from page 80A)

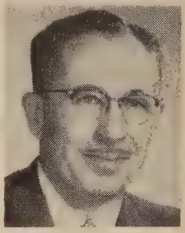
Peter G. Smee (M'47–SM'52) has been appointed manager of Microwave Systems Design for General Electric's Communication Products Department in Lynchburg, Va. The appointment was announced by I. T. Corbell, the department's manager of Microwave Engineering.

P. G. Smee

Mr. Smee is a native of Lincoln, England and received his technical training in the United Kingdom. He holds several U. S. patents in the communication field. He joined General Electric at Electronics Park, Syracuse, N. Y., in 1946 and has specialized in microwave engineering for the past several years.

❖

John M. Thompson (J'27–A'28–M'47–SM'53) has been named as Vice President and General Manager of ITEMLAB, Inc. located at Port Washington, N. Y. He will head the activities of this concern in the fields of environmental testing, design, research and development.


J. M. Thompson

He has been laboratory chief of the Rome Air Development Center's Test Facility Laboratory for the past ten years and prior to that was associated with Watson Laboratories, Signal Corps Engineering Laboratories and the USVA for a total of 25 years government service.

Mr. Thompson is a senior member of the Instrument Society of America, a member of the American Institute of Electrical Engineers, American Society of Metals and Institute of Environmental Sciences and associate member of the American Society of Heating, Refrigeration and Air Conditioning Engineers.

❖

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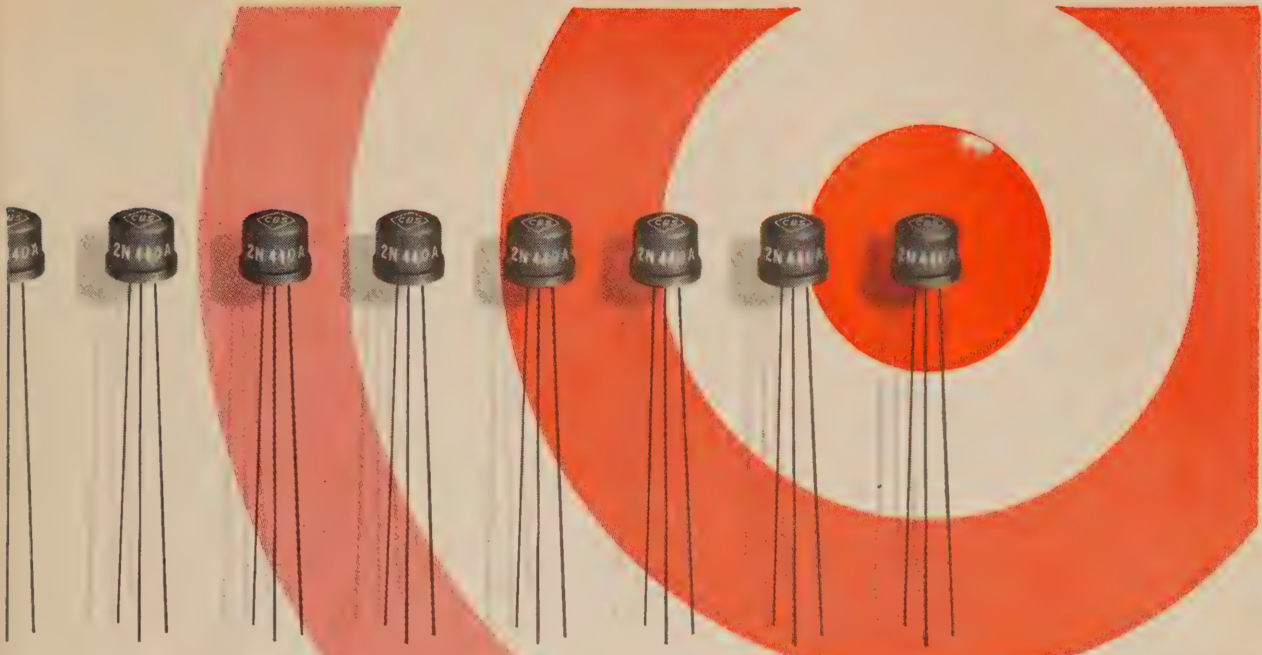

TARGET... better than 99.99% switching transistor survival

CBS NPN germanium switching transistors are being delivered to a military project specification with an objective of 99.99% survival in 1000 hours. This means that only one transistor in 10,000 can fail due to parameter changes . . . and catastrophic failure rate is even lower.

CHECK THESE SPECIAL RELIABILITY CONTROLS

100% PRODUCTION

- Every crystal identified throughout production
- Die thickness maintained within ± 0.00005 inch
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- Microscopic inspection of all critical operations
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- Detergent bomb testing at 100 psig
- Radiflo testing to 10^{-12} standard cc/sec

RELIABILITY

- Voltage-biased, 55°C on 1000 hour life
- Storage, 85°C on 1000 hour life
- Intermittent operation, 150 mw for 1000 hour life
- Samplings 100 times larger than MIL-T-19500A
- Product identified with crystal for field survival analysis

ENVIRONMENTAL TESTING

- Shock, 500 G for 1 millisecond
- Vibration, 20 G for 20-2000 cps
- Soldering of leads, 260°C for 10 sec
- Fatigue of leads, 16 oz. pull, three 90° arcs

YOUR INQUIRIES INVITED

Inquiries regarding *your* special reliability requirements for NPN germanium switching transistors are invited. Please call direct . . . or your local sales office.

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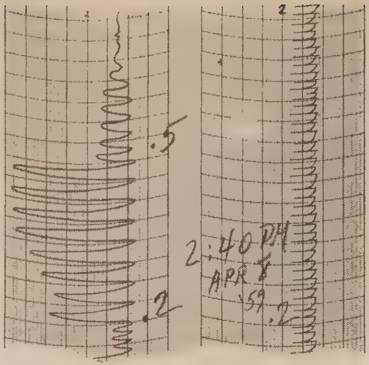

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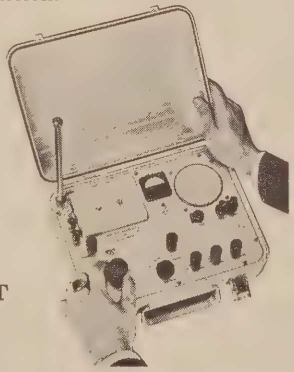
Time...
have significance!

...and with today's accelerating technology, the need for the most accurate time reference available becomes more acute. It *is* available ...and free; the standard time and frequency transmissions of the National Bureau of Standards radio stations WWV and WWVH are accurate to better than 1 part in 50 million and are placed at the disposal of anyone having a receiver capable of tuning to one or more of the transmitting frequencies.

The new Model WWVT receiver, designed especially for remote operations under extreme environmental conditions, is a highly-sensitive crystal-controlled instrument capable of utilizing WWV and WWVH transmission.



Model
WWVT

A 6-position dial switches *instantly* to any Standard Frequency—2.5, 5, 10, 15, 20 or 25 mc. It is small, light-weight and rugged—sealed metal case and potted components, all transistorized and battery operated, and has better than 2 mv sensitivity. Priced at $690.00. Model WWVTR (rack mount) $725.00

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Section Meetings

AKRON

"Computer Activities in Europe and Russia," Dr. N. R. Scott, University of Michigan. 1/19/60.

ALAMOGORDO-HOLLOMAN

"Teaching Machines and Tomorrow's Education," Dr. R. F. Mager, Fort Bliss Human Research Unit. 1/18/60.

ALBUQUERQUE-LOS ALAMOS

Conducted tour of Lovelace Radiation Laboratory plus four papers by Dr. White of Lovelace Foundation. 11/17/59.

"For Better Conversations," Dr. J. P. Molnar, Sandia Corp. Fellow Awards Dinner meeting. 2/1/60.

ATLANTA

"Quantum Electronics," Dr. M. W. Long, Georgia Tech. 1/22/60.

BALTIMORE

"Military and Industrial Applications of Infrared," A. H. Canada, Institute for Defense Analyses, Washington, D. C. 2/1/60.

BAY OF QUINTE

"Theory of Relativity," Dr. G. A. Harrower, Queens University. 1/20/60.

CENTRAL FLORIDA

"Infrared Technology & Physics," Dr. S. S. Ballard, University of Florida. 1/14/60.

CENTRAL PENNSYLVANIA

"Fission, Fusion and the Future," F. A. Kramer, Public Service Electric, Gas Co. 11/17/59.

"The USSR Forges Ahead," Dr. J. L. McLucas, Singer, Inc. 12/15/59.

"Trends in Electronic Instrument Design," Roy Mershon, Weston Instruments Co. 1/19/60.

CHICAGO

"Hot Electrons from Cold Cathodes," Dr. A. M. Skellet, Tung-Sol Electric, Inc. 9/11/59.

"SAGE—A Data Processing System for Air Defense," S. J. Hansen and C. A. Zraket, Mitre Corporation. 10/9/59.

"Molecular Engineering, the Future of Electronics," Dr. G. C. Sziklai, Westinghouse Electric Corp. 11/13/59.

"The Place of Ionospheric Scatter in World Communications," W. H. Collins and K. E. Oittinen, Page Communications Engineers, Inc. 12/11/59.

"Circuit Design Using Tunnel Diode Devices," Dr. K. K. N. Chang, RCA Labs. 1/8/60.

CHINA LAKE

"Parametric Amplifiers," Dr. C. J. Carter, Space Technology Lab. 11/9/59.

"Electron Microscopes," Dr. Ernst Bauer, U. S. Naval Ordnance Test Station. 1/11/60.

CLEVELAND

"Thermo Electricity," C. J. Frank, Westinghouse Electric Corp. 1/21/60.

COLUMBUS

Inspection Tour—Electronics Laboratories Facility, North American Aviation. Comments by David Leonard of the Company. 2/9/60.

DALLAS

"Tactics of Air Launching a Ballistic Missile for Satellite Reconnaissance," Eaton Adams, Convair Fort Worth. 1/19/60.

"Esaki and Other Special Diodes," G. C. Dacey, Bell Telephone Labs. 2/4/60.

"Information Theory," W. A. Youngblood, University of Texas. 2/11/60.

(Continued on page 88A)

MINCOM
announces a new double-duty magnetic tape system
the CM-100
records & reproduces 6 SPEEDS

Greater bandwidths at lower speeds in both analog and pulse recording/reproducing (for example, 500 kc at 60 ips). All in one compact standard rack. Details? Write for brochure.

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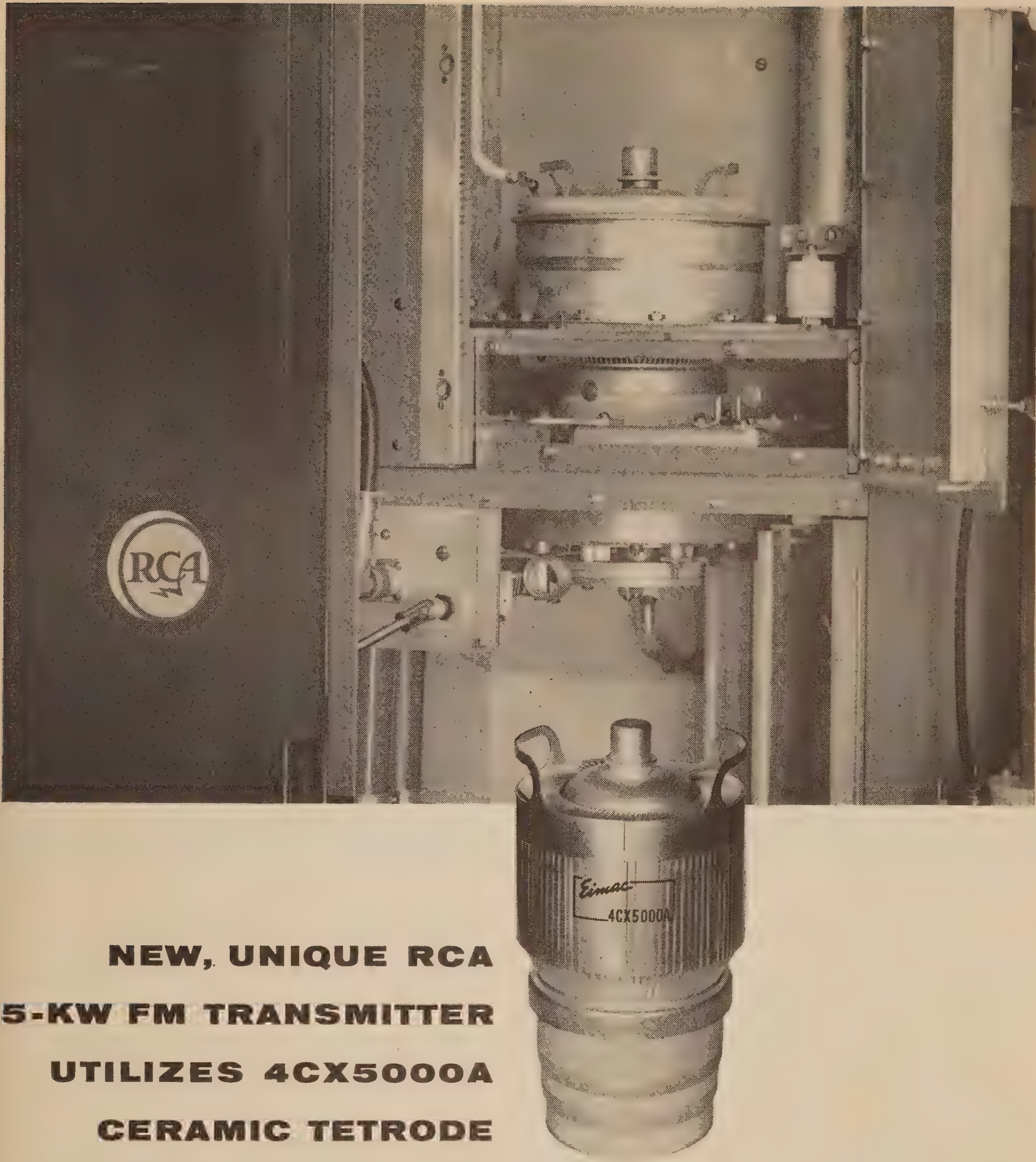


NEW, UNIQUE RCA 5-KW FM TRANSMITTER UTILIZES 4CX5000A CERAMIC TETRODE

RCA has recently developed a unique new 5-KW FM transmitter which utilizes the new technique of multiplexing. This provides simultaneous transmission of two or more program channels on the same RF carrier to meet increased demands of FM stations for additional program services.

The PA stage of the new BTF-5B transmitter is composed of a single Eimac 4CX5000A ceramic tetrode, which produces the 5000-watt output. This tetrode offers high power gain and excellent stability to assure faithful transmission of the broadband multiplex signals.

That's why the 4CX5000A was the logical choice of discriminating RCA engineers. Its many exclusive ceramic design features help to make possible this conservatively rated, high power, air-cooled transmitter.

These ceramic extras are now available in more than forty Eimac tube types—used in many types of communication, pulse and industrial equipment.

EITEL-McCULLOUGH, INC.

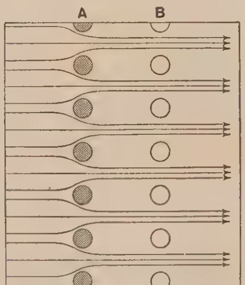
San Carlos, California

Eimac

Nothing is NEWER than
like G-E Shadow Grid...
anode...New products
New engineering: direct-

MEANS LOWEST-NOISE PENTODE!

The new Shadow Grid tube is an advanced concept applied by General Electric. It makes possible high-gain pentode performance at a low noise level found up to now only in triodes. Electron flow is channeled *between* the wires of the screen grid. There is minimum contact of electrons with grid. Consequently, noise-producing screen current is held to a minimum. A plate-to-screen current ratio of 25 to 1 can be obtained with new General Electric Type 6FG5 for TV tuners.



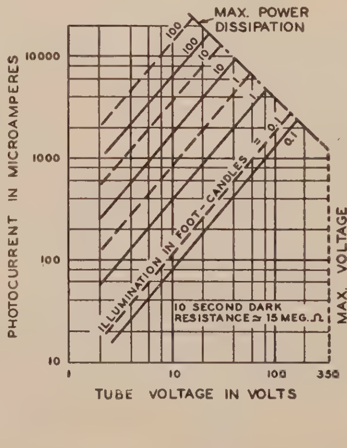
Electron flow from cathode past control grid is guided by electrostatic field in the vicinity of

Shielding grid (A) into streams passing between the wires of

Screen Grid (B), thus bypassing the screen grid and continuing to the plate.

ACTUATES RELAYS DIRECTLY!

General Electric's new 7427 cadmium-sulphide photoconductive tube is so sensitive to light variations, and can handle so much current (400 mw max dissipation), that the tube will operate a relay without amplification. Your costs are reduced. Spectrum of the 7427 matches the human eye. Check performance below:



Left: average characteristics, Type 7427

——AC (RMS) operation

- - - - DC operation

Note this new tube's high sensitivity to light, with large current capacity. In series with a relay, the G-E 7427 helps form a simple, economical circuit which will handle scores of lighting, industrial, other control functions.

ubes . New concepts

ew materials like 5-ply

ike 7427 phototube.

eated cathode in 3DG4.

CUTS HEAT IN TV RECEIVERS!

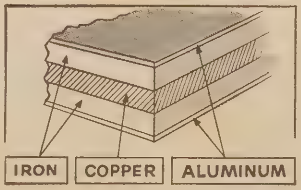
Less heater power...less total power for set...less heat generated! The new General Electric 3DG4 power rectifier tube with direct-heated cathode brings you all three benefits. Special 3-ply cathode requires no filament, teams up with a new high-internal-reflectance plate material for maximum efficiency. Total power required is 42% less than the 5V3. Compare:

	NEW 3DG4	5V3
Heater power	12.5 w	19.0 w
Total watts in tube	29	50
Bulb temperature	171 C	206 C
Output current	350 ma	350 ma

NO "HOT SPOTS" ON ANODES!

General Electric has pioneered the use of 5-ply bonded material for tube anodes. Greatly superior in heat conduction and radiation, the new material prevents the formation of "hot spots" when tubes are running full-load. Gives sustained top-performance capability to a large and growing list of G-E receiving types.

Copper promotes the even distribution and faster dissipation of anode heat. Iron for strength. Aluminum for surface protection.



RECEIVING TUBE DEPARTMENT OFFICES:

New York, WI 7-4065, 6, 7, 8....Boston, DE 2-7122....Washington, EX 3-3600....Chicago, SP 7-1600
Dallas, RI 7-4296....Los Angeles, GR 9-7765, BR 2-8566....San Francisco, DI 2-7201.

Progress Is Our Most Important Product

GENERAL ELECTRIC

411-101

If relays cause you as much trouble as they do us, you will undoubtedly welcome information on how to get rid of them. Probably the most fashionable way to do the switching is to use transistors, and as a public service Sigma hereby offers some application data toward this end. The Search for Truth must go on.

Right off the bat, it must be conceded that transistors have the edge in several important physical and dynamic respects. Relays are certainly bigger, heavier and slower, and their useful life is nowhere near infinite—primarily because they all have such old-fashioned things as moving parts. Nor are relays immune to unlimited shock and vibration (the best we've been able to do on a subminiature type, and keep it operating within spec, is 30 g's to 5000 cycles).

There are a few things relays *are* good for, however, even though "Relayized" may never sell a single product. For instance: signal circuits can be isolated from load circuits . . . signal and load can be AC or DC, in any combination . . . circuits with high voltage to ground present no particular problems, and relatively high voltage loads can be handled . . . inductive loads can be switched "off" when they're supposed to be off. On "sliding" or slowly varying signals, the right relay will also provide clean, positive switching and it won't fry if the circuit develops a mild defect. It is true, if not grammatical, to say that a relay is many orders more "off" and several orders more "on" than those other things.

The fact that relay contacts more closely approximate the ideal switch—no ohms one way and infinite ohms the other way—also means something when dry circuit switching is your problem. With loads in the order of 0.1 microwatt, a properly designed relay can provide dependable switching.

Further, if 3-position, polar, center-stable switching (Sigma "Form X") is needed, a single relay will do the job. And if the requirement calls for having the switch "remember" and stay in the last switched position, a polarized, magnetic latching relay (our "Form Z") will do just that without stand-by power.

There are also such considerations as *cost* (where the switching is of the pinball machine variety), *stability* as a function of temperature, and *amplification* (10,000:1 load to signal ratio), that lean in favor of relays. But the main ones are those mentioned earlier—which we're banking on to keep us from going bankrupt this year. In the meantime, we're looking around for diversification possibilities—something in a good solid state, perhaps.

HOW TO AVOID RELAYS*

*or, Ten Easy Steps to Utopia.

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Section Meetings

(Continued from page 84A)

DENVER

"Telebit-Digital Telemetry on Explorer VI," Dr. G. E. Mueller, Space Technology Laboratories. 11/19/59.

"Large Scale Electronic Computers and Scientific Computers," Dr. J. J. Sopka, National Bureau of Standards. 1/21/60.

DETROIT

"Surgical Techniques for Reconstructing the Middle Ear," Dr. H. F. Schuknecht, Henry Ford Hospital; "Psychophysical Studies of Hearing," W. P. Tanner, Jr., University of Michigan Research Institute. 1/8/60.

ELMIRA-CORNING

"Advances in Screen Structure and Data Distribution for the ELF Display System," Dr. E. A. Sack, Westinghouse Electric Corp. 1/11/60.

"Recent Advances in Field Emission," Dr. F. Charbonnier, Linfield Research Institute. 2/1/60.

EL PASO

"Technical Training Is Now Being Automated," Dr. R. F. Mager, Fort Bliss Human Research Section. 1/7/60.

EMPORIUM

"Automation for Quality Control Testing of Electron Tubes," R. A. McNaughton, Sylvania Electronic Tubes. 1/19/60.

EVANSVILLE-OWENSBORO

"Nuclear Radiation & Electronic Equipment," J. R. Crittenden, G.E. Co. 1/20/60.

"The Next Twenty Years in Space," Dr. Leo Steg, G.E. Co. 2/10/60.

FLORIDA WEST COAST

"IRE—A Look at Headquarters," Dr. R. L. McFarlan, IRE President. 2/8/60.

FORT HUACHUCA

"Log Periodic Antennas," Dr. Duhamel, Collins Radio Co. 1/25/60.

FORT WORTH

"Moon Bounce Communications Systems," Dr. A. Straiton, Univ. of Texas. 1/15/60.

GAINESVILLE

"Current Problems in Infrared Physics and Technology," Dr. S. S. Ballard, University of Florida. 2/10/60.

HAMILTON

"The Vidicon and Related Tubes," F. Townsend, Westinghouse Elec. Corp. 1/11/60.

"A Bright Radar Display System," Dr. T. W. East, Raytheon Canada, Ltd. 2/8/60.

HAWAII

"Engineering Aspects of the Integrated Fire and Police Department Communications System," Harold Chun, Honolulu Police Department. 10/14/59.

"Novel Compression and Expansion Methods for Audio and Video Use," W. R. Aiken, Kaiser Engineers. 11/11/59.

"Ionospheric Scatter Systems," J. S. McLeod, Page Communications. 1/13/60.

HOUSTON

Business meeting. 1/19/60.

HUNTSVILLE

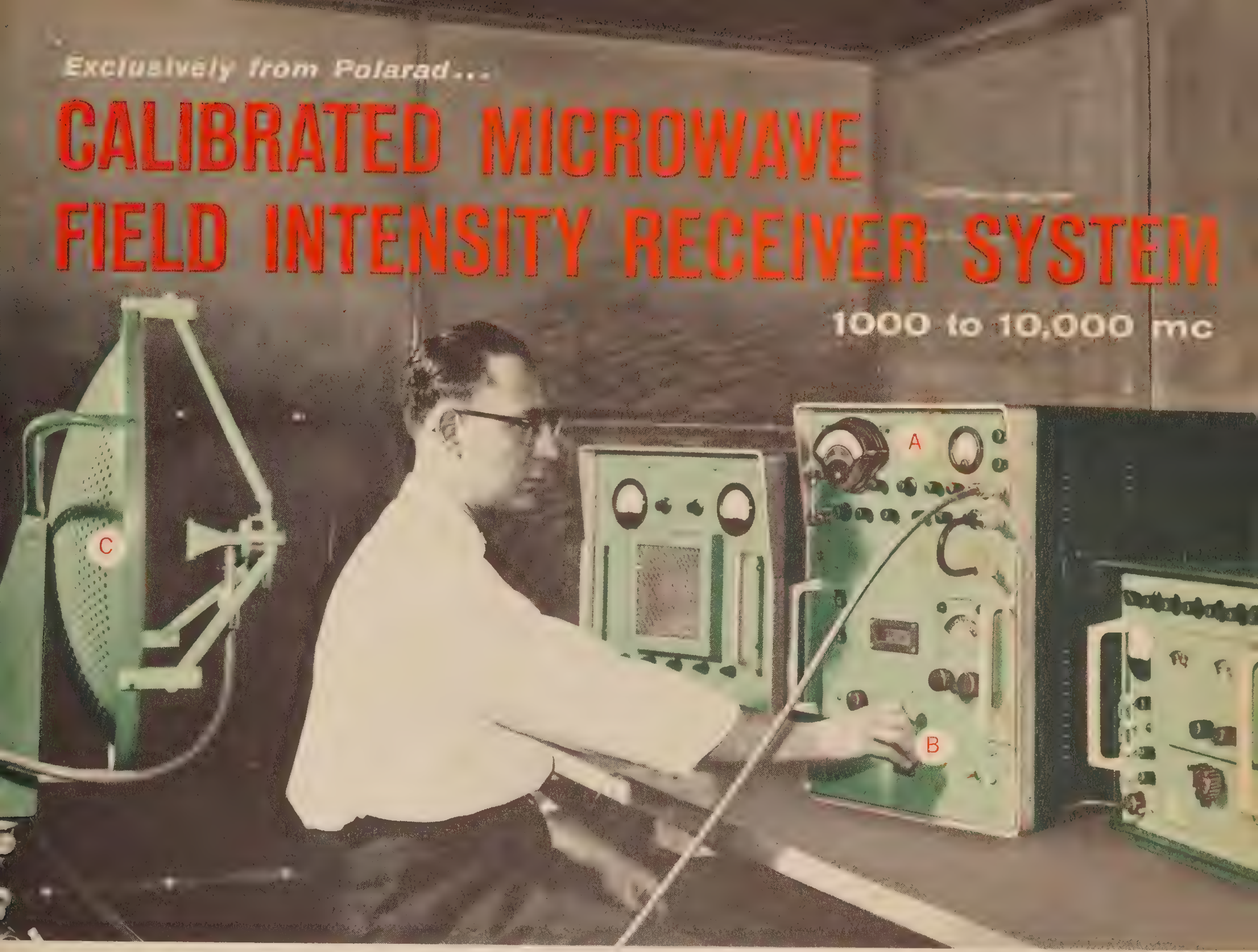
"Pulse Duration Modulation Techniques," Dr. T. G. Antzack, Electro-Mechanical Research, Inc. 1/28/60.

(Continued on page 92A)

Exclusively from Polarad...

CALIBRATED MICROWAVE FIELD INTENSITY RECEIVER SYSTEM

1000 to 10,000 mc



Model FIM being used to check radiated interference against MIL-I-26600

e complete integrated Model FIM includes:

- Ⓐ **A monitoring unit.** Meter indicates average, peak or quasi-peak value of r-f signals. Outputs for video, audio and recorder.
- Ⓑ **R-F Plug In Tuning Units.** Four units cover the frequency range 1000 to 10,000 mc. UNI-DIAL tuning control tunes both the receiver and internal signal calibrator.
- Ⓒ **Calibrated Antenna System** complete with tripod and a calibrated omni-directional Broadband antenna or a separate directional antenna to match each R-F tuning unit.

Use this precision instrument for antenna pattern and shielding analysis, r-f power and voltage measurements, determination of field intensity, signal propagation patterns and other microwave parameters.

Determines absolute level of radiation, leakage and interference by comparison with an internally generated CW signal. Also measures signal susceptibility

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INSTRUMENTS

MAIL THIS CARD for specifications. Ask your nearest Polarad representative (in the Yellow Pages) for a copy of "Notes on Microwave Measurements."

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CORPORATION**

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Representatives in principal cities

MEP

POLARAD ELECTRONICS CORPORATION:

Please send me information and specifications on:

☐ Model FIM Calibrated Microwave Field Intensity Receiver
☐ Model N-1 Precision Noise Generator (see reverse side of page)

POLARAD

My application is____________________

Name____________________

Title__________Dept.__________

Company____________________

Address____________________

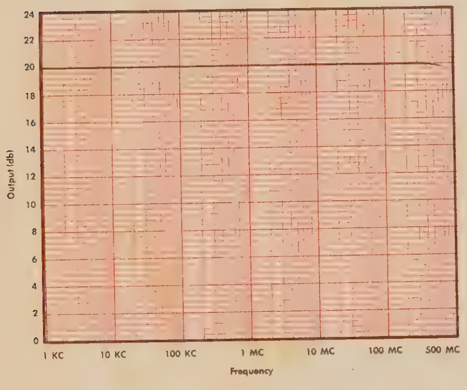
City__________Zone_____State__________

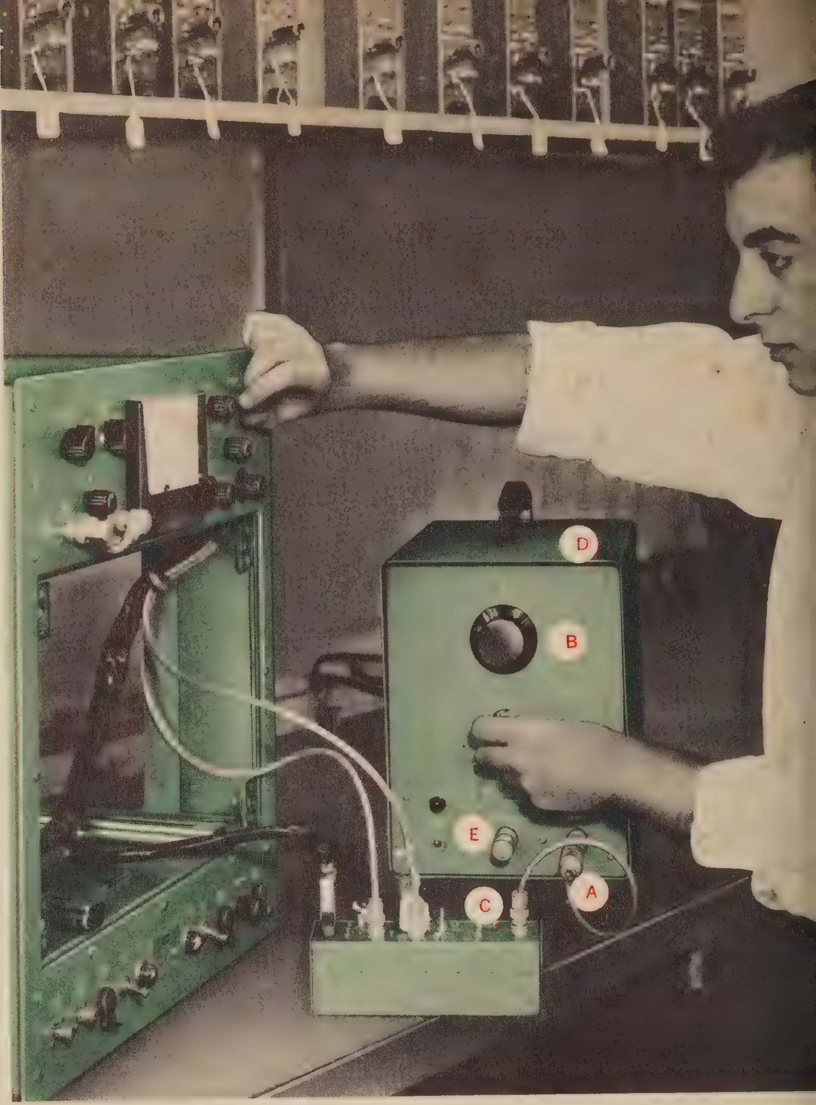
New from Polarad...

PRECISION NOISE GENERATOR

- Ⓐ 1 kc to 500 mc
- Ⓑ 1 to 20 db, adjustable
- Ⓒ 0.25 db output accuracy
- Ⓓ Long-life, low-maintenance noise tubes
- Ⓔ Stable output

Noise output constant over entire frequency range. Maintains set level into any terminating impedance, 50 to 10,000 ohms.





Production line noise figure measurements, made rapidly and accurately with Polarad Model N-1.

The Polarad Model N-1 is a small, compact, portable noise generator with easy-to-operate controls. The Model N-1 (Digitized variable output level controls — 0 to 20 db. Calibrated 1 db steps — fine vernier between each step.) is entirely self-contained, including power supplies. Use it for direct noise figure measurements of vacuum tube or transistor amplifiers, receivers and oscillators.

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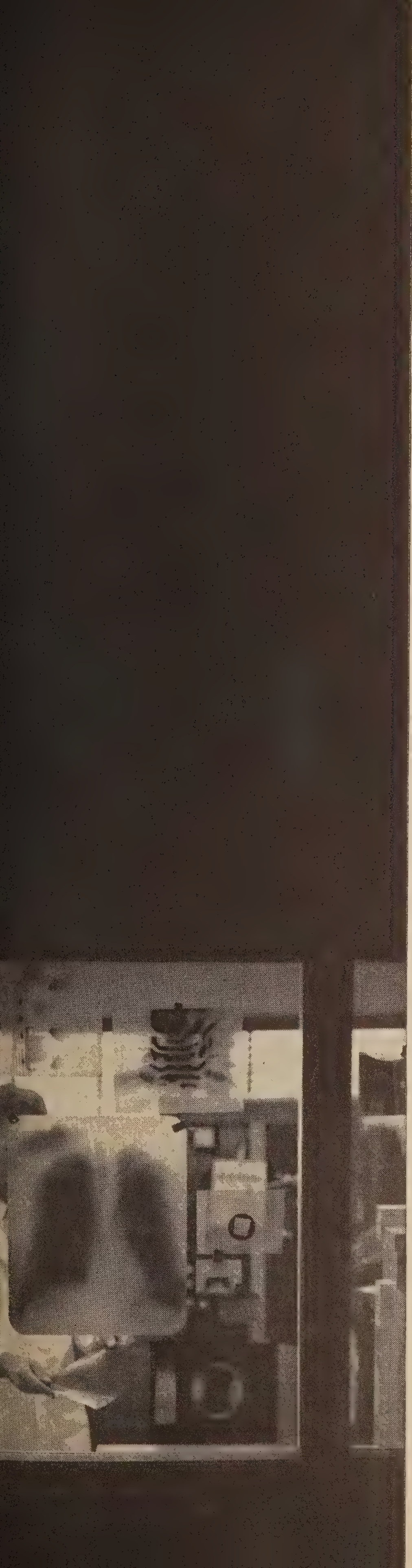


One of a series

Payoff in portable photons

Samarium-145, Samarium-153, Gadolinium-153.
Scientists at the General Motors Research Laboratories began three years ago to measure and re-evaluate the nuclear characteristics of these rare earth isotopes — their half-lives, photon emissions, thermal neutron cross sections.

Conclusion: the radioisotopes had attractive possibilities in industrial and medical radiography, emitting almost pure gamma rays or X-rays (photons) in the low energy range of 30 to 100 kev.

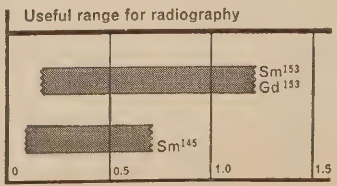
The transition from research to hardware came through two key developments. First, cermet pellets were fabricated using only a few milligrams of the rare earth oxides. Then the irradiated pellets were packaged in special bullet-size holders.

The resulting small, sealed radiographic sources are now being field and laboratory tested. Two excellent applications: "inside-out" checks of hollow shapes inaccessible to X-ray tubes, and radiography of thin steel sections and low density materials such as aluminum or human bone. For example, a recent medical milestone was a chest radiograph of a living person made with a Sm^{153} source. The portable exposure unit to shield the source weighed only 18 pounds.

This isotope radiography program is but one example of the work underway in GM Research's modern isotope laboratory — work that means, through science, "more and better things for more people."

General Motors Research Laboratories

Warren, Michigan



Aluminum thickness (inches)

Sm^{153} exposure unit.

TMI-1a analysis of 18 IRIG FM/FM channels with slight pre-emphasis.

known for speed and accuracy

Panoramic
TELEMETRY TEST INSTRUMENTS

A range of reliable equipments for
- Subcarrier Spectrum tests
- Telemetry Package Checkout
- Subcarrier discriminator and oscillator calibration
- Data reduction frequency reference
- Power Spectral Density Plots

NEW: Model TMC-411 Simultaneous 11-Point Frequency Calibrator. Transistorized, miniaturized. Long term accuracy .001% provides 11 equally spaced frequencies within all IRIG FM/FM channels, 18 simultaneous channel outputs. Source for data reduction multiple frequency references. Only 7" high.

Model TMI-1a, 350 cps to 85 kc: for rapid monitoring of all or any part of subcarrier spectrum, checks pre-emphasis, analyzes subcarrier, cross talk, VCO deviations, etc.

Model TMC-1: 1) Sets up TMI-1a for quick checks of each IRIG channel for deviation, spillover, etc. 2) furnishes channel end limits and center markers for precise deviation analysis 3) 3 point calibrator for all IRIG channels, accuracy 0.02%. Model CHS-1 performs Model TMC-1 use #1 only.

All these . . . plus fast, versatile Spectrum Analyzers (subsonic thru microwave), Power Spectral Density Analyzers . . . Panadaptors . . . for expanded applications.

Write, wire, phone today for detailed technical bulletins on the equipment you need. Ask for NEW CATALOG DIGEST . . . and get on our regular mailing list for "THE PANORAMIC ANALYZER" featuring application data.

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Section Meetings

(Continued from page 88A)

ITHACA

"Electronic Beam Parametric Amplifiers," Dr. Robert Adler, Zenith Radio Corp. 1/14/60.

"The Response of Electronic Equipment to Acoustic Noise Fields," N. Doelling, Bolt Beranek & Newman, Inc., 2/11/60

KANSAS CITY

Business meeting. 12/8/59.

"Sound Transmission in Ocean Waters and Some of Its Problems," C. M. Wallis, University of Missouri. 1/12/60.

LITTLE ROCK

"Significance of Noise and Noise Figure in Radio Communication," Alden Packard, AR & T Electronics, Inc. 1/18/60.

"Methods of Characterizing Semiconductor Surfaces," Dr. C. G. Peattie, Texas Instruments, Inc. 2/15/60.

LONDON (ONTARIO)

"The D.R.T.E. Digital Computor," C. D. Florida, Department of National Defence, Ottawa. 1/5/60.

LONG ISLAND

Introduction to Lecture Series. Dr. C. J. Mundo, Jr. Arma Corp.; "Psycho-Acoustics," Dr. W. Rosenblith, MIT. 10/1/59.

"Spectroscopy and Biological Cell Structure," Dr. L. Ornstein, Mt. Sinai Hospital. 10/8/59 (2nd of Lecture Series).

"Neurophysiology of Human Control Processes," Dr. H. Grundefest, Columbia University. 10/15/59 (3rd of Lecture Series).

"Cell Structure and the Electron Microscope," Dr. K. R. Porter, Rockefeller Institute. 10/22/59 (4th of Lecture Series).

"Neurophysiology of Sight," Dr. H. Hartline, Rockefeller Institute. 10/29/59 (5th of Lecture Series).

"Electronic and Computer Techniques in Diagnosis of Heart Diseases," W. E. Tolles, W. Carbery, C. Steinbery, Airborne Instruments Laboratory. (6th of Lecture Series). 11/5/59.

"Strategy of Deterrence," Harry Davis, Rome Air Development Center. 1/12/60.

LOS ANGELES

"Aerospace Power for National Security," Gen. O. J. Ritland, ARDC. 2/4/60.

LOUISVILLE

Tour of Standiford Field Radar Flight Control Center with comments by the F.A.A. Staff. 8/27/59.

"WAVE's New Building and Facilities," Wilbur Hudson, WAVE. 9/24/59.

"Jet Aircraft Control and Flight Simulator," V. M. Yahne, Kentucky Air National Guard. 10/22/59.

"Lighting of Radio and Television Towers," O. W. Towner, WHAS. 11/20/59.

LUBBOCK

"Interference at a Common Tower," David Land, Motorola. 1/26/60.

MIAMI

"Electronic Education and Engineering in India," Dr. P. H. Craig, U. S. State Department. 1/15/60.

MILWAUKEE

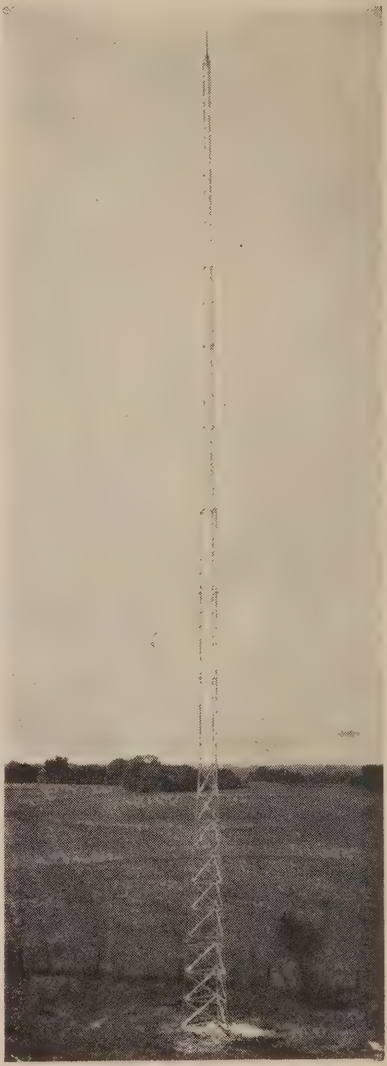
"Radiometry," Ted Seling, A. C. Spark Plug Co. Presentation of Fellow Award. 1/20/60.

MONTREAL

"Measured Retaliation," M. Jennings, Raytheon Corp. 1/20/60.

(Continued on page 94A)

New ROHN
SELF SUPPORTING
COMMUNICATION TOWER



★ 130 ft. in height, fully self-supporting!
★ Rated a true HEAVY-DUTY steel tower, suitable for communication purposes, such as radio, telephone, broadcasting, etc.
★ Complete hot-dipped galvanizing after fabrication.
★ Low in cost—does your job with BIG savings—yet has excellent construction and unexcelled design! Easily shipped and quickly installed.

FREE *details gladly sent on request. Representatives coast-to-coast.*

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"Pioneer Manufacturers of Towers of All Kinds"

NEW DELCO 50-AMP. TRANSISTORS

HIGHER CURRENT THAN EVER BEFORE FOR MILITARY AND COMMERCIAL USE

	2N1518	2N1519	2N1520	2N1521	2N1522	2N1523
Maximum Collector Current (Amps.)	25	25	35	35	50	50
Maximum Collector to Base Volts, Emitter Open, Max Ico 4ma	50	80	50	80	50	80
Minimum Open Base Volts (1-Amp. Sweep Method)	40	60	40	60	40	60
Maximum Saturation Volts at Maximum Collector Current	0.7	0.7	0.6	0.6	0.5	0.5
Gain at Ic at 15 Amps.	15-40	15-40	17-35	17-35	22-45	22-45
Minimum Gain at Maximum Collector Current	12	12	12	12	12	12
Thermal Resistance Junction to Mounting Base (°C/Watt)	0.8	0.8	0.8	0.8	0.8	0.8

Characteristics at 25°C   Maximum Junction Temperature 95°C

A new family of high current transistors featuring the 50-ampere 2N1522 and 2N1523. Two 25- and two 35-ampere types round out the line. All thoroughly tested and completely reliable. Available in production quantities. Call or write your nearest Delco Radio sales office for full product information and applications assistance.

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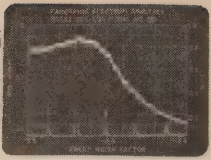
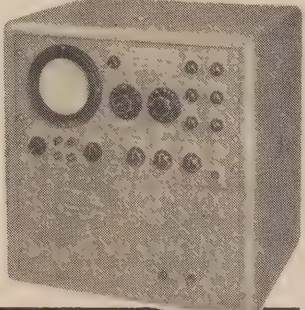
Noise spectrum analysis using internal video smoothing filter. Noise envelope average vs. frequency seen in readily interpreted plot. Internal marker pips are 500kc apart.



more applications maximum economy



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SPA-3/25
SPECTRUM ANALYZER
200cps-25mc

One compact, low-cost unit for all these uses . . . and MORE:

Video Band Analysis
Broadband Noise Studies
Communications Channel Analysis
Telemetry Subcarrier Channel Analysis
Frequency Response Plotting of filters, video networks, to 15mc, etc. (with companion sweep generator Model G-6)

Combining the most desirable features of a whole series of equipments, Panoramic's "workhorse" Model SPA-3/25 features:
• 0-3mc sweep width continuously calibrated • Variable center frequency control cailibrated from 0 to 23.5 mc • Adjustable resoultion; selectivity, 200cps to 30kc • Variable sweep rate 1cps to 60 cps • Lin, 40db log and square law amplitude scales • High sensitivity: 20uv full scale • Calibrated 100 db input attenuators

Also available: Model SPA-3, 200cps-15mc. Same at SPA-3/25, except variable center frequency control is calibrated 0 to 13.5mc.

Write, wire, phone NOW for detailed specification bulletin . . . NEW Catalog Digest . . . and regular mailing of "THE PANORAMIC ANALYZER," featuring application data.

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Section Meetings

(Continued from page 92A)

NEWFOUNDLAND

"Ladies Nite," Dinner Meeting and Dance. 12/14/59.

"Supervisory Control of Hydro-Electric Plants," M. Gladden, Newfoundland Light & Power Co. 1/21/60.

NEW YORK

"Wall Street Analyst's Look at Electronics," Discussion by Panel consisting of G. Edgar, M. Loeb; M. Heilbrun, Rhoades & Co.; A. Cohn, Bache & Co.; Miss P. Shulder, Merrill Lynch, Pierce, Fenner & Smith, Inc. 12/2/59.

NORTH CAROLINA

"Sampling Techniques for Automatic Waveform Analysis," M. R. Sundquist, Bell Telephone Labs. Presentation of Fellow Award. 1/15/60.

"Subscriber Line Data Transmission Systems," P. J. Grunfelder, Western Electric Co., Inc. 2/19/60.

NORTHERN ALBERTA

"Filters and Duplexers," Dr. W. V. Tilston, Sinclair Radio Labs. 1/19/60.

NORTHWEST FLORIDA

"Recent Biological Experiments in Ballistics Missiles," Dr. D. E. Stullken, NATC, Pensacola. 12/15/59.

OKLAHOMA CITY

Tour of Amplitron Installation and Air Navigation Facilities, Will Rogers Field, Oklahoma City. 1/12/60.

"Use of Transistors in Seismic Work," J. D. Delbridge, Shell Oil Co. 2/9/60.

ORLANDO

"Current Problems in Infrared Physics & Technology," Dr. S. S. Ballard, University of Florida; Film: "Bomarc Weapon System." 1/13/60.

"Considerations in Design and Use of Direct Writing Recording Systems," Dr. A. Miller, Sanborn Co. 1/20/60.

"Facts About IRE Headquarters—Present Activities and Future Plans," Dr. R. L. McFarlan, IRE President. 2/1/60.

Seminar on "The Role of a Nuclear Reactor in a University," Dr. T. J. Thompson, MIT; Dr. W. Kerr, University of Michigan; W. J. Clapp, Florida Power Corp.; Dr. W. B. Harrison, Georgia Tech.; Dr. Glenn A. Greathouse, University of Florida; Dr. J. A. Wethington, University of Florida. Presiding was Dr. Walter H. Zinn, General Nuclear Engineering Corp. 2/13/60.

OTTAWA

"Design Problems in Developing Oscilloscopes," M. B. Crouch, Tektronix, Inc. 1/14/60.

Five different subjects by University Students. Presentation of Fellow Award. 2/4/60.

PHILADELPHIA

"Design of the UNIVAC-LARC System," J. P. Eckert, H. Lukoff and A. B. Tonik of Remington Rand. 1/6/60.

PHOENIX

"Signal-Flow Graphs in Sampled-Data Systems," Dr. J. M. Salzer, Ramo-Wooldridge Corp. 1/19/60.

PITTSBURGH

"Instrumentation—Past and Present," R. D. Wyckoff, Gulf Research and Development Corp. 10/5/59.

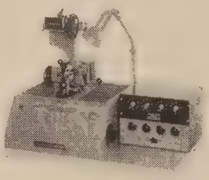
"The Systems Approach to Molecular Electronics," Dr. A. W. McCourt, Westinghouse Air Arm Division. 10/19/59.

Field tour of Greater Pittsburgh Airport Air Traffic Control Center. 11/9/59.

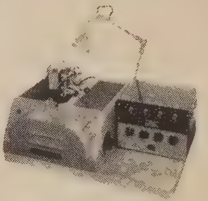
"Recent Developments in Thermoelectric Cool-

(Continued on page 96A)

BOESCH
subminiature toroidal coil winders



MODEL SM



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SM winds 1/16" I.D. toroids. New MINITOR winds 1/32" I.D. Write for complete data.

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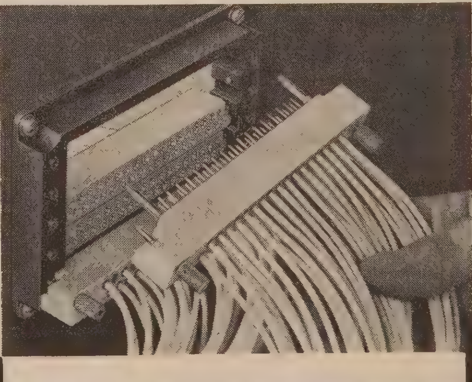
BOESCH MANUFACTURING CO., INC., DANBURY, CONN.

crimp-type, snap-locked contacts
Modular
HYFEN®
connector
feed-thru, multiple insert

Makes possible the design of lighter and more compact equipment. Each insert holds 35 contacts. Frames available for 5 or 8 inserts.



BURNDY
For complete information, write: OMATON DIVISION, BURNDY—Norwalk, Connect.
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recti/riter
Texas Instruments Incorporated

recti/riter® recorders prove what every engineer knows . . . SIMPLICITY MEANS RELIABILITY

What simpler and more reliable actuating device can you employ in an amperage-voltage-frequency recording instrument than a d'Arsonval galvanometer . . . a trouble-free horseshoe magnet and a coil of wire? The same is true of the exclusive "recti/rite"® system . . . a simple, shock resistant trigonometric linkage that straightens the arc described by the galvanometer metering arm, changing curvilinear motion to rectilinear motion.

All the other "recti/riter" recorder features which contribute to this instrument's multi-industry acceptance and hardworking reliability are equally simple: The optional a-c or d-c drives couple directly with chart speed change gears to allow ten chart speeds; all routine operations and adjustments are performed "up front"; the non-corrosive, honed metal alloy pens, closed ink system, and large capacity ink well give you long, consistent writing performance.

With all their simplicity and reliability, "recti/riter" recorders are offered in extremely wide and useful Basic Recorder Ranges (Dual channel recorders offer combination of any two ranges):

Two Cycle Pen Response

D-c Milliampere Ranges	¼ ma to 100 ma
A-c Ampere Ranges	0.25 A to 25 A
D-c Ampere Range	100 mv for use with standard shunts
Expanded Scale A-c Voltage Ranges	80-130 V, 160-260 V, 320-520 V
A-c and D-c Voltage Ranges	10 V to 1000 V
Frequency Ranges	50, 60, 400 cps

Five Cycle Pen Response

D-c Milliampere Range	5 ma

Ask the TI engineer about *customized* recorders for your OEM applications. Don't settle for any recorder until you know all the facts on the complete "recti/riter" recorder line.

TEXAS INSTRUMENTS
INCORPORATED
GEOSCIENCES & INSTRUMENTATION DIVISION
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The proved "recti/riter" recorder is a companion to the new "servo/riter"* recorder.

*"servo/riter" is a trademark of Texas Instruments

new rapid tests of SSB transmissions with ONE compact multi-purpose spectrum analyzer

PANORAMIC'S
SSB-3

. . . simple
. . . versatile
. . . low-priced

Now, in one convenient package, all the equipment you need to set up, adjust, monitor, trouble-shoot SSB and AM transmissions!

- 60 db dynamic range
- 60 cps hum sidebands measurable to —60 db
- Stable tuning head with 2 mc to 40 mc range with direct reading dial
- Sensitive spectrum analyzer with pre-set sweep widths of 150, 500, 2000, 10,000 and 30,000 cps with automatic optimum resolution
- Continuously variable sweep width up to 100 kc
- Two-tone generator with separate audio oscillators with independent frequency and amplitude controls. Output 2 volts max. per tone into 600 ohm load
- Internal calibrating and self checking circuitry

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RADIO PRODUCTS, INC.

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OWens 9-4600
Cables: Panoramic, Mt. Vernon, N. Y. State

Section Meetings

(Continued from page 94A)

ing Devices and Power Generation," Dr. S. J. Angello, Westinghouse Electric Corp. 12/7/59.

"The New Sound"—A special non-technical non-commercial demonstration of new and old techniques for recording by a special RCA demonstration team. 12/14/59.

PORTLAND

Tour of Tektronix Plant. 12/17/59.

Demonstration Lecture on the ESIAC Algebraic Computer, by Dr. M. Morgan, Electro-Measurements, Inc. 1/23/60.

"Time Division in Communication," K. Searcy, Pacific Telephone & Telegraph Co. 2/10/60.

Panel discussion on "An Impedance Plethysmograph-Instrumentation and Clinical Application" and "A Myograph, Instrumentation and Clinical Application," Panel members: Loren Park, Dr. R. J. Underwood, Dr. R. E. Rinehard, and Dr. D. Michael. 2/11/60.

QUEBEC

"The Case for Special Quality Tubes," D. S. Simkins, Rogers Electronic Tubes and Components. 1/27/60.

REGINA

Conducted tour of Regina Airport Radar Installation. 11/27/59.

ROME-UTICA

"Interface Problems in System Design," A. Kunze, Rome Air Development Center. 1/26/60.

SALT LAKE CITY

"A New Look At Relativity," John Anderson, Retired. 11/3/59.

"Traveling Wave Tube Oscillograph," Dr. R. Grow, University of Utah. 12/8/59.

"Pulse Doppler Radar," A. W. Vodak, Sperry Utah Engineering Lab. 1/14/60.

SAN ANTONIO-AUSTIN

"Parametric Amplifiers," Dr. K. Kotzebue, Texas Instruments. 10/16/59.

"Electronic Circuitry for Ultrasonic Application," W. A. Gunkel, Southwest Research Institute. 11/20/59.

"Maximizing Information Rate in Data Systems," Dr. W. A. Youngblood, University of Texas. 12/12/59.

"Techniques of Audio Frequency Measurements," Hoyt Foster, Kelly AFB. 12/18/59.

Presentation of Fellow Award. 1/22/60

SAN DIEGO

"Electroluminescence," S. H. Boyd, Stromberg-Carlson. 1/6/60.

"Optimization of Airborne Special-purpose Computers," R. Williamson, Librascope. 2/3/60.

SCHENECTADY

"Digital Shaft Encoders," R. Knapp, RPI. 1/21/60.

"The Scavenger Amplifier," Dr. W. K. Volkers, Millivac Instrument Corp. 2/9/60.

SHREVEPORT

"Microwave Communications," A. K. Urschel and Mr. Davis, Collins Radio. 1/5/60.

"Transistor Characteristics and Circuits," Prof. E. W. E. Owen, Louisiana State University. 2/2/60.

SOUTH BEND-MISHAWAKA

"Doppler Navigation Radar," R. E. Tollefson, Collins Radio. 9/24/59.

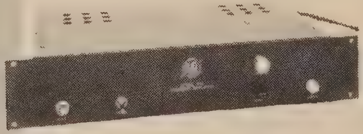
"The IRE in the Space Age," Dr. Ernest Weber, IRE President. 10/14/59.

Tour of RCA Whirlpool Research Laboratories with comments by Dr. D. Cutler. 10/29/59.

"Magnetics—Key to Modern Control," E. V. Wier, Magnetics, Inc. 12/3/59.

(Continued on page 98A)

Wide Band Amplifier Model 530



GENERAL DESCRIPTION

The Model 530 Wide Band Amplifier has been designed to fill a need for an amplifier used principally for voltage amplification of CW or pulsed signals.

This model has many applications in the laboratory and also for television distribution systems. It may be used to increase the output from signal sources within its frequency range, and its bandwidth of 300 mc's makes it ideal for amplifying millimicrosecond pulses.

PRICE $330.

SPECIFICATIONS

Bandpass	10 KC to 300 MC
Voltage Gain	18 db
Input Impedance	135 ohms
Output Impedance	150 ohms
Max. Output Power (into Matched Load)	.08W
Max Output Voltage (into Matched Load)	3.5 Vrms
Max. Peak Pluse Output	7 V pos. or neg.
Rise Time	Less than 2×10^9 sec
Dimensions	19″ front panel—16″ wide, 9″ deep 3½ high. Power supply included.
Gain Control	Provided on front panel
Tube Complement	Two cascaded stages of eight 6AK5

INSTRUMENTS FOR INDUSTRY, Inc.
101 New South Road, Hicksville, L. I., N.Y.

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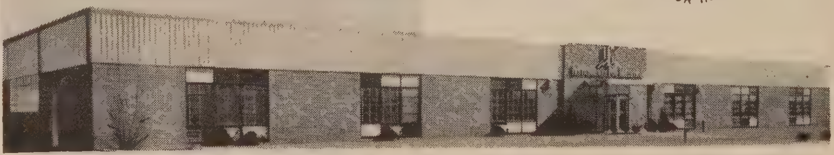
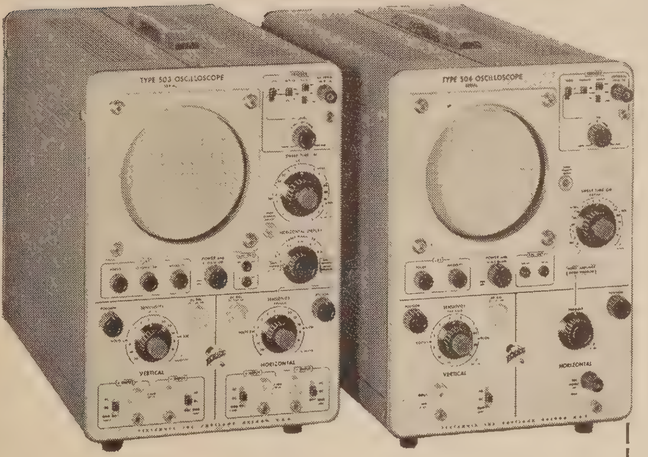


Graduate engineers with two or more years of circuit application in the fields of electronics or physics are invited to meet with Mr. John Hicks in an informal interview or send complete resume to: Dir. Personnel, IFI, 101 New South Road, Hicksville, New York.

2 NEW

GENERAL-PURPOSE OSCILLOSCOPES introduce TEKTRONIX QUALITY to the DC-to-450 KC RANGE



The Tektronix Type 503 and Type 504 are the first of a family of new oscilloscopes for the DC-to-450 KC application area.

- **Both feature high reliability, simple operation, light weight.**
- **Each excels in performance characteristics in its class.**
- **Both now established as production instruments.**

Prices

TYPE 503 . . . . $625
TYPE 504 525
f.o.b. factory

Tektronix, Inc.

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Phone MItchell 4-0161 • TWX—BEAV 311 • Cable: TEKTRONIX

TYPE 503

The Type 503 is a differential-input X-Y oscilloscope with the additional features—linear sweeps, dependable triggering, sweep magnifier, bright trace, amplitude calibrator—desirable for general-purpose applications.

FREQUENCY RESPONSE
dc to 450 kc

VERTICAL AND HORIZONTAL AMPLIFIERS
Differential input at all attenuator settings.
1 mv/cm to 20 v/cm in 14 calibrated steps.
Continuously variable between steps, and to approximately 50 v/cm uncalibrated.
Constant input impedance at all sensitivities (standard 10X probes can be used).

SWEEP RANGE
1 μsec/cm to 5 sec/cm in 21 calibrated steps.
Sweep time adjustable between steps, and to approximately 12 sec/cm uncalibrated.

SWEEP MAGNIFICATION
X2, X5, X10, X20, and X50 Magnification.

AMPLITUDE CALIBRATOR
500 mv and 5 mv peak-to-peak square-wave voltages are available from front panel.

3-KV ACCELERATING POTENTIAL
5-inch Tektronix crt provides bright trace, 8-cm by 10-cm viewing area.

EASY TRIGGERING
Fully automatic, amplitude-level selection on rising or falling slope of signal, or free-run (recurrent). AC or DC coupling, internal, external, or line.

REGULATED POWER SUPPLIES
All critical dc voltages electronically-regulated, plus regulated heater supplies for the input stages of both amplifiers.

SIZE AND WEIGHT
13½″ h, 9¾″ w, 21½″ d—approximately 29 lbs.

TYPE 504

The Type 504 has the basic features desirable for most general-purpose applications — sensitive vertical amplifier, linear sweeps, easy triggering, amplitude calibrator.

FREQUENCY RESPONSE
dc to 450 kc

VERTICAL AMPLIFIER
5 mv/cm to 20 v/cm in 12 calibrated steps.
Continuously variable between steps, and to approximately 50 v/cm uncalibrated.
Constant input impedance at all sensitivities (standard 10X probe can be used).

SWEEP RANGE
1 μsec/cm to 0.5 sec/cm in 18 calibrated steps.
Sweep time adjustable between steps, and to approximately 1.2 sec/cm uncalibrated.

AMPLITUDE CALIBRATOR
500 mv and 25 mv peak-to-peak square-wave voltages are available from front panel.

HORIZONTAL INPUT
0.5 v/cm, with variable attenuator.

3-KV ACCELERATING POTENTIAL
5-inch Tektronix crt provides bright trace, 8-cm by 10-cm viewing area.

EASY TRIGGERING
Fully automatic, amplitude-level selection on rising or falling slope of signal, or free-run (recurrent). AC or DC coupling, internal, external, or line.

REGULATED POWER SUPPLIES
All critical dc voltages electronically-regulated, plus regulated heater supplies for the input stages of the vertical amplifier.

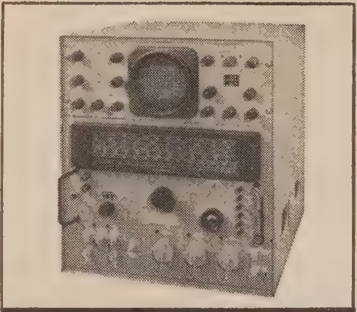
SIZE AND WEIGHT
13½″ h, 9¾″ w, 21½″ d—approximately 29 lbs.

Rack-mounting models will be available, of course!

TEKTRONIX FIELD OFFICES: Albuquerque, N. Mex • Atlanta, Ga. • Baltimore (Towson, Md) • Boston (Lexington, Mass.) • Buffalo, N.Y. • Chicago (Park Ridge, Ill) • Cleveland, Ohio • Dallas, Texas • Dayton, Ohio • Denver, Colo. • Detroit (Lothrup Village, Mich.) • Endicott (Endwell, N.Y.) • Greensboro, N.C. • Houston, Texas • Kansas City (Mission, Kan.) • East Los Angeles, Calif. • West Los Angeles, Calif. • Minneapolis, Minn. • New York City Area (Albertson, L.I., N.Y. • Stamford, Conn. • Union, N.J.) • Orlando, Fla. • Philadelphia, Pa. • Phoenix, (Scottsdale, Ariz.) • San Diego, Calif. • San Francisco (Palo Alto, Calif.) • St. Petersburg, Fla. • Syracuse, N.Y. • Toronto (Willowdale, Ont.) Canada • Washington, D.C. (Annandale, Va.)

TEKTRONIX ENGINEERING REPRESENTATIVES: Hawthorne Electronics; Portland, Oregon • Seattle, Washington. Tektronix is represented in twenty overseas countries by qualified engineering organizations.

extreme sensitivity 10 mc to 44,000 mc



PANORAMIC'S SPA-4 SPECTRUM ANALYZER

MORE USEABLE SENSITIVITY

BAND	RF SENSITIVITY*
10 — 420 MC	—95 to —105 dbm
350 — 1000 MC	—90 to —100 dbm
910 — 2200 MC	—90 to —100 dbm
1980 — 4500 MC	—80 to — 90 dbm
4.5 — 10.88 KMC	—80 to — 95 dbm
10.88 — 18.0 KMC	—70 to — 90 dbm
18.0 — 26.4 KMC	—60 to — 85 dbm
26.4 — 44.0 KMC	—55 to — 85 dbm

*measured when signal and noise equal 2X noise

Using one tuning head which contains one triode and two Klystron oscillators, Model SPA-4 offers more exclusive advantages for applications demanding extreme sensitivity, stability, versatility, accuracy.

- Three precisely calibrated amplitude scales—40 db log, 20 db linear, 10 db power.
- Two independent frequency dispersion ranges—continuously adjustable—0-70 mc and 0-5 mc. Negligible internal frequency modulation permits narrow band analysis of FM problems.
- Variable I.F. bandwidth from 1 kc to 80 kc.
- Push-button frequency selector.
- Synchroscope output with 40 db gain.
- Accurate measurement of small frequency differences. A self-contained marker oscillator, modulated by a calibrated external generator, provides accurate differential marker pips as close as 10 kc.

Tremendous flexibility and many unique advances of Panoramic's compact SPA-4 make it unsurpassed for visually analyzing FM, AM and pulsed signal systems; instabilities of oscillators; noise spectra; detection of parasitics; studies of harmonic outputs; radar systems and other signal sources.

Write, wire or phone today for detailed SPA-4 bulletin.

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Section Meetings

(*Continued from page 96A*)

SOUTH CAROLINA

"The Development of the Modern Electron Tube," Dr. W. R. Ferris, University of South Carolina. 2/5/60.

SYRACUSE

"Centralized Railroad Traffic Control," C. F. Mulranen, N.Y. Central R.R. 1/21/60.

TOLEDO

"Tomorrow's Communications," D. F. Jones and R. F. Palomo, Ohio Bell Telephone Co. 1/14/60.

TUCSON

"Log Periodic Antennas," Dr. R. H. Du Hammel, Collins Radio Co. 1/26/60.

TULSA

"A Low Phase Distortion Seismic Amplifier," Dr. H. B. Ferguson, Jersey Production Research Co. 1/21/60.

VIRGINIA

"High Power Radiation Hazards (HERO)," J. N. Payne, U. S. Naval Weapons Lab. 1/8/60.

WASHINGTON

"Integrated Electronics," Dr. D. A. Jenny, RCA Labs. 1/26/60.

"How Are We Conserving Our Natural Resource—The Radio Spectrum?" panel discussion with Commodore E. M. Webster, Moderator. Panel members: T.A.M. Craven, FCC; Capt. P. Miles, Office of Civil Defense & Mobilization; W. H. Watkins, FCC. 2/1/60.

WILLIAMSPORT

"English Contributions to Television," F. Rutter, Westinghouse Electronics. 1/27/60.

"Propulsion for Space Flight," Dr. E. Petrick and H. Szymanowski, Curtiss-Wright Corp. 2/1/60.

WINNIPEG

"Transient Response from Frequency Response by Digital Computer Methods," M. Ito, University of Manitoba; "Mercury Arc Rectifiers, Rectifier Transformers and Rectification Systems," M. Mayer, University of Manitoba. 12/2/59.

"Antenna Research," Dr. W. V. Tilson, Sinclair Radio Lab. 1/20/60.

SUBSECTIONS

BUENAVENTURA

"Some Aspects of Instrumentation for Ballistic Missiles and Other Rockets," John Masterson, Pacific Missile Range; "Closed Circuit TV and Swept Band Transmission Measuring Set Demonstrations," S. Wilson, Hallamore Electronics Co. 1/13/60.

EAST BAY

"High Speed Data Reduction," J. Russell, Lawrence Radiation Lab. 10/5/59.

EASTERN NORTH CAROLINA

"Soil Moisture Content by Neutron Scattering," W. F. Troxler, Troxler Electrical Lab. Election of officers. 1/8/60.

"Semi-conductor Charged-particle Detectors," J. L. Blankenship, Oak Ridge National Lab. 2/12/60.

FAIRFIELD COUNTY

"Technical Manpower, A Vital Resource," Dean A. H. Jacobson, Pennsylvania State University. 1/21/60.

KITCHENER-WATERLOO

"Reproduction of Heart Sounds," L. M. Steinberg, University of Toronto. 1/25/60.

(*Continued on page 102A*)

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ACCELEROMETERS
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Advanced Home Study and Residence Courses in Electronics, Automation and Industrial Electronics Engineering Technology

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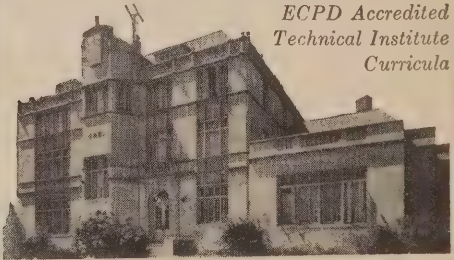

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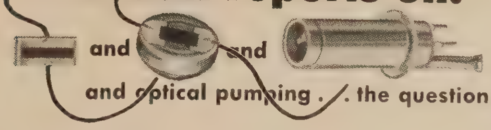


and and . . . sunshine for the plastics man who worries . . . organic chemistry and optical pumping . . . the question of whether or not instrumentation people really need ultra-fast film

Infrared detectors for sale

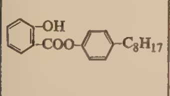
Our involvement in infrared detectors has deepened.

Pictured at the top of this page are, respectively, the simplest kind of *Kodak Ektron Detector* with a rectangular sensitive area of any reasonable dimensions, available either in a 3-pin miniature cable socket or unmounted with resolderable leads; an "immersed" detector with detecting substance deposited on the plano surface of a radiation-collecting lens; a detector mounted in a Dewar for cooling by cryostat. We also deposit detecting substance in separated or intricate configurations as ingenuity, under necessity's goad, may provide.

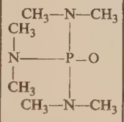
Since any of these physical forms can now be provided with any of six different kinds of lead sulfide or lead selenide depositions, as governed by spectral sensitivity, response time, temperature, and ambient humidity, the print gets quite fine in a folder we are publishing this month to guide the selection of *Kodak Ektron Detectors.*

A free copy is available from Eastman Kodak Company, Apparatus and Optical Division, Rochester 4, N. Y. It is designed to make the sale with minimum further correspondence. To give you an idea, the off-the-shelf, one-only price scale starts from $14.50.

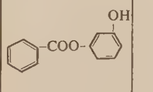
Corruption can be arrested



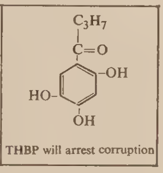
OPS will arrest corruption



HPT
will arrest corruption



RMB
will arrest corruption



THBP will arrest corruption

When plastics stand up to cracking, crazing, embrittlement, gumming, and discoloration with the passage of time and sunshine, it's OK to credit the integrity of the maker's name.

The concept of integrity is more readily grasped than is the principle that every C-C bond, every O-H bond, every C-Cl bond, every C=N bond, has its own price—a photon of ultraviolet radiation just right in energy to snap it. Thus corruption of plastics, a chain reaction like other corruptions, begins. A rival substance that grabs off the u-v photons first and degrades their energy will delay the corruption for a long time.

Other corruptions, initiated by atmospheric oxygen, can be delayed by compounds that stop the action by supplying hydrogen at a critical juncture. Of course, choice in inhibitors is greatly restricted by many considerations of physical and chemical compatibility.

Obviously, we think we have made a good choice in these new ones:

Eastman Inhibitor OPS (p-Octylphenyl Salicylate), at 1 to 5% levels, a preventive of the photo-oxidation that forms deleterious carbonyl groups in polyethylene and polypropylene.

Eastman Inhibitor HPT (Hexamethylphosphoric Triamide), very pale, water-soluble, a liquid u-v inhibitor for use with a heat stabilizer in poly(vinyl chloride) at 1 to 2%.

Eastman Inhibitor RMB (Resorcinol Monobenzoate), a non-coloring u-v inhibitor at 1% levels for transparent cellulose acetate butyrate. Superior to phenyl salicylate. Also protects cellulose acetate, cellulose acetate propionate, polystyrene, poly(vinyl chloride), and ethylcellulose.

Eastman Inhibitor THBP (2,4,5-Trihydroxybutyrophenone), an antioxidant for polyolefins and various paraffin waxes. May be added in solid form directly during the milling process, or in solvent solutions to dry powders or melts, at 0.01 to 0.1% concentrations. Especially valuable for absence of stain at the low concentrations.

Isn't it fun how in the chemical industry practically everybody is simultaneously practically everybody else's customer, supplier, and competitor! Data sheets and development samples (for those in a position to evaluate them) from Eastman Chemical Products, Inc., Kingsport, Tenn. (Subsidiary of Eastman Kodak Company).

Man passing out dotriacontane

The atomic physicists are looking for substances against which polarized free electrons can bounce without having their spins inverted. The physicists want to coat a substance like that on the walls of evacuated glass vessels. It should have no free or unpaired electrons, no crystal structure. To an electron scooting by, such a molecule should appear magnetically inert. The small residual pressure tolerable in the vessel should be mostly of rubidium vapor and not of the non-inverting substance. Also the coating must have good transmittance at around the 8000A wavelength of the radiation fed to excite the rubidium.

"Optical pumping," the theme these experiments share, has to do with the manipulation of quantum levels so that emission from the excited alkali metal atoms can be tuned with great elegance. Pressure to improve understanding of the phenomena comes from the need for instrumentation to study the Van Allen radiation belts and for satellite-borne atomic clocks to check out Einstein's old predictions about the meaning of time as told from a moving timepiece.

Some little samples of non-inverting substance were passed out at a recent optical pumping conference by a man who may well have bought the material from us as *Dotriacontane* (Eastman 3555). Spermacetti wax once had a role in physics as the material of the standard candle which defined candlepower. When chemists attacked it, they found cetyl palmitate, $C_{16}H_{33}OCOC_{15}H_{31}$. We have to make a long, uniform, inert, homogeneous molecule out of that. In effect, the two oxygens the whale put in the middle of the molecule are replaced by hydrogens. That is *Dotriacontane.* The climax, if any, will come when word filters through that it has done the job.

The moral is that with some 3800 organic compounds to milk, we need never be at a loss for words. They're all stocked by Distillation Products Industries, Eastman Organic Chemicals Department, Rochester 3, N. Y. (Division of Eastman Kodak Company).

1600—no waiting

How come after all those promises we have made to innumerable instrumentation people over the years that some day there would be 16mm, 35mm, and 70mm film as fast as *Kodak Royal-X Pan Recording Film* now is—Index 1600—how come we now find ourselves in the ridiculous position of being able to make it at a greater rate than they're buying it? How come?

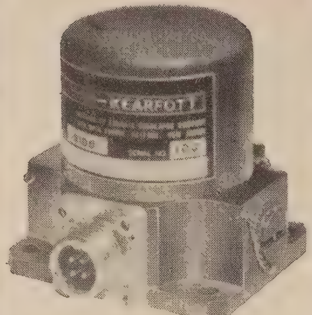
Don't they know that a note or phone call to Eastman Kodak Company, Photo Recording Methods Division, Rochester 4, N. Y., will set up the channel to supply it through a local dealer?

Price quoted is subject to change without notice.

This is another advertisement where Eastman Kodak Company probes at random for mutual interests and occasionally a little revenue from those whose work has something to do with science

Kodak
TRADEMARK

BASIC BUILDING BLOCKS FROM KEARFOTT



ELECTROHYDRAULIC SERVO VALVE

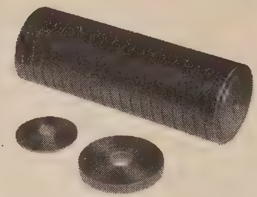
Kearfott's unique approach to electrohydraulic feedback amplification design has resulted in a high-performance miniature servo valve with just two moving parts. Ideally suited to missile, aircraft and industrial applications, these anti-clogging, 2-stage, 4-way selector valves provide high frequency response and proved reliability even with highly contaminated fluids and under conditions of extreme temperature.

TYPICAL CHARACTERISTICS

Quiescent Flow	0.15 gpm
Hysteresis	3% of rated current
Frequency Response	3 db @ 100 cps
Supply pressure	500 to 3000 psi
Temperature-Fluid & Ambient	−65° F to +275° F
Flow Rate Range	.3 to 10 gpm
Weight	10.5 ounces

Write for complete data.

BASIC BUILDING BLOCKS FROM KEARFOTT



FERRITES

Kearfott's Solid State Physics Laboratory formulates, fires and machines permanent magnet ferrite materials of various compositions. Typical high-efficiency array utilizes Kearfott PM-3 ferrite material with specially designed pole pieces to produce a design both smaller and lighter than other arrays of equivalent magnetic field strength. Because magnets may be custom engineered to specific requirements, user is not restricted to stock magnet types, thereby providing greater latitude in parameters for focusing arrays. Pole pieces may also be provided according to specification, with the added assurance that, because of special Kearfott design techniques, B axial magnetic fields approximately 10% higher than those generally obtained in standard types may be produced.

TYPICAL CHARACTERISTICS

Peak Magnetic Field Strength	1200 gauss
Period	0.560 in.
Length	5.64 in.
Inside Diameter of Pole Pieces	0.400 in.
Outside Diameter	2.0 in.
Weight	3.2 pounds

Write for complete data.

BASIC BUILDING BLOCKS FROM KEARFOTT

INTEGRATING TACHOMETERS

Kearfott integrating tachometers, special types of rate generators, are almost invariably provided integrally coupled to a motor. They feature tachometer generators of high output-to-null ratio and are temperature stabilized or compensated for highest accuracy integration and rate computation. Linearity of these compact, lightweight tachometers ranges as low as .01% and is usually better than ± .1%.

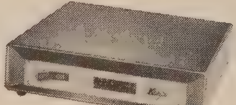
TYPICAL CHARACTERISTICS

	Size 11 (R860)
Excitation Voltage (400 cps)	115
Volts at 0 rpm (RMS)	.020
Volts at 1000 rpm (RMS)	2.75
Phase shift at 3600 rpm	0°
Linearity at 0-3600 rpm	.07
Operating Temperature Range	−54° +125°

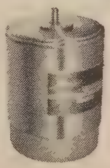
Write for complete data.

Miniature Floated Gyro

Precise Angle Indicator



20 Second Synchro



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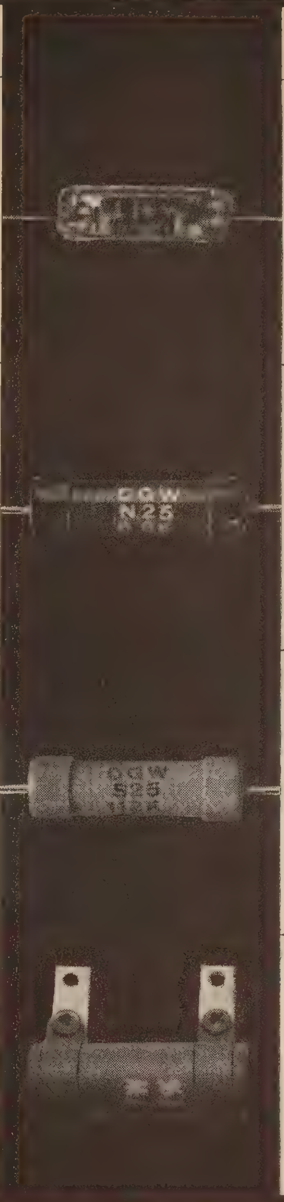
Engineers: Kearfott offers challenging opportunities in advanced component and system development.



TYPE	SIZE	RESISTANCE (ohms)	WATTAGE	TC
NF **Fusion sealed.** Glass encapsulation is fusion sealed to leads and has zero moisture absorption. Exceeds requirements of MIL-R-10509C, Char. B.	NF60 NF65	100 to 100 K 100 to 360 K	⅛ @ 70° C. ¼ @ 70° C.	±.03%/° C. from −55° C. to +150° C., ref. to 25° C.
N **Fixed film.** Extremely low noise level. 0.1 microvolt/volt. Derating to 140° C. Average resistance change after 5000 hrs. is less than 1%. Exceeds MIL-R-10509B, Char. X specs.	N20 N25 N30	10 to 500 K 10 to 1.5 meg. 30 to 4.2 meg.	½ @ 40° C. 1 @ 40° C. 2 @ 40° C.	±.03%/° C. from −55° C. to +105° C., ref. to 25° C.
S **Fixed film: high temperature.** Less than 0.35% resistance change after 1000 hrs. of load-life tests at max. dissipation. Exceeds MIL-R-11804C, Char. P.	S20 S25 S30	10 to 500 K 10 to 1.5 meg. 30 to 4.2 meg.	**120° C. 40° C.** ½ 1 1 2 2 4	±.03%/° C. from −55° C. to +235° C., ref. to 25° C.
R **Power.** Essentially non-inductive in high-frequency operations. Inherent noise level less than 0.1 microvolt per volt. Exceptional moisture resistance and overload capacity. Exceeds MIL-R-11804C.	R31 R33 R35 R37 R39	10 to 70 K 30 to 150 K 20 to 300 K 20 to 500 K 40 to 1 meg.	7 @ 40° C. 13 @ 40° C. 25 @ 40° C. 55 @ 40° C. 115 @ 40° C.	±.05%/° C. from −55° C. to +235° C., ref. to 25° C.

Why you save ounces and inches with Corning MIL resistors

Fuse a tin oxide coating to a piece of special glass. Spiral a helix in it. Attach leads. You have a unique resistor, smaller and lighter than other designs.

Why unique? Because the coating is an integral part of the glass base. It cannot come off or change its position during jarring or jouncing.

This simple, rugged, extremely reliable resistor will take all the environmental stresses created by the space age without changing its performance a whit.

The construction has exceptional low-noise and stable-temperature characteristics.

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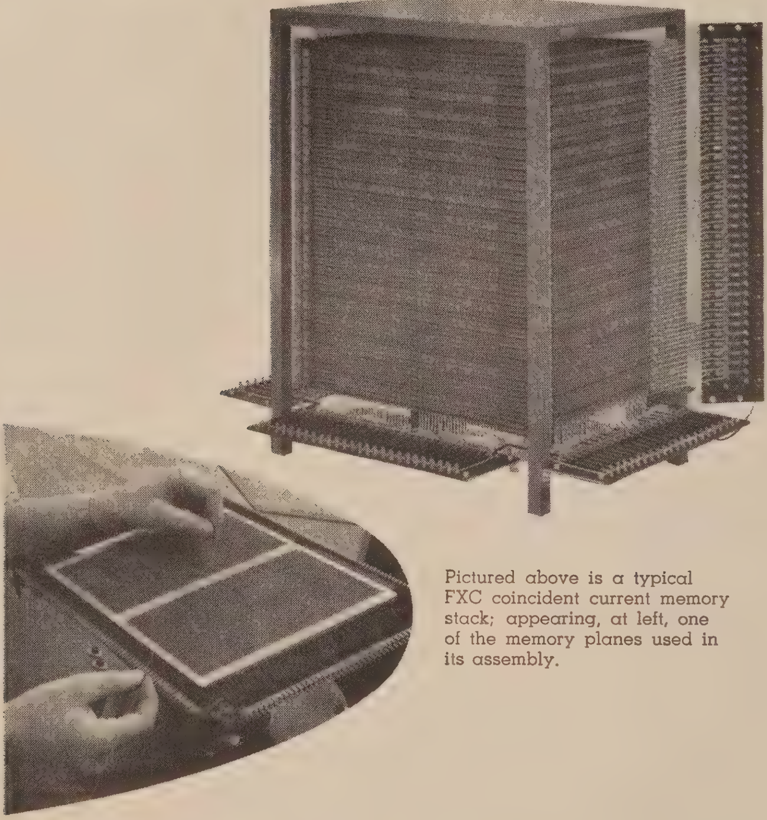

Pictured above is a typical FXC coincident current memory stack; appearing, at left, one of the memory planes used in its assembly.

Time was when the problem of "remembering" placed practical limitations on the speed and capacity of computers. Not so, today, because of a FXC-developed component called the *coincident current memory stack.* Main reason for the outstanding success of this important advancement in magnetic ceramics rests in FXC's ability to meet the computer industry's requirements for ferroxcube cores for recording heads . . . pulse transformers . . . coincident current planes, stacks and similar *precisely engineered* products. Call FXC's Computer Engineering Dept. whenever you need help on a ferroxcube application.

Say ferroxcube when you need ferrite.

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Section Meetings

(*Continued from page 98A*)

LANCASTER

"Some Aspects of Metallurgy in Semiconductors," Dr. F. D. Rosi, RCA. 12/9/59.

LAS CRUCES-WHITE SANDS

"Tracking Earth Satellites with Minitrack," P. A. Lantz, National Aeronautics and Space Administration. 2/9/60.

MEMPHIS

"Manufacture and Precision of Radio Crystals," Dr. Charles Ray, University of Tennessee. Election of officers. 1/30/60.

MONMOUTH

"Useful Energy from Controlled Fusion," Dr. M. A. Heald, Swarthmore College. 1/20/60.

NEW HAMPSHIRE

"Medical Electronics," A. M. Grass, Grass Instrument Co. 1/20/60.

NORTHERN VERMONT

"Submarine Electronics," Com. J. G. Gillmore, U. S. Naval Submarine School. 1/18/60.

ORANGE BELT

"Ionic Propulsion," Y. C. Lee, Aerojet General. 10/13/59.

"Quality Instrument Manufacturing," W. D. Meyers, Hewlett-Packard. Tour of California Polytechnic Electronic Laboratory Facilities. 11/10/59.

Tour of Kaiser Steel Fontana Plant and Plant Communications. Mr. Klussman, Kaiser Steel. 1/11/60.

PANAMA CITY

Business meeting. 2/10/60.

PASADENA

"Tunnel Diodes," Dr. C. J. Carter, Space Technology Labs. 1/8/60.

READING

"Industrial Communications," H. Campbell, GAI-Tronics Corp. Tour of Semi-conductor department of Western Electric Company plant in Laureldale. 11/18/59.

"Project Vanguard—A Step Into Space," H. F. Eckenroth, Martin Co. 12/11/59.

RICHLAND

"Elements of Reliability," A. L. Ruiz, G. E. Co. 11/4/59.

"The Precision Measurement of Extremely High Voltages," H. V. Larson, G. E. Co. 1/27/60.

SAN FERNANDO VALLEY

"You Take the Eyewitness, Give Me the Physical Evidence," Prof. L. V. Jones. Tour of Anheuser-Busch Brewery. 1/13/60.

SANTA ANA

"Earth Movements," John Healy, Seismological Lab. 1/12/60.

WESTCHESTER

"Application of Electronics to Photogrammetric Techniques in Modern Map Making," M. M. Thompson, U. S. Department of Interior. 1/20/60.

WESTERN NORTH CAROLINA

Two films: "Crystals—An Introduction" and "Brattain on Semiconductor Physics." 1/22/60.

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It's Valuable

A pulse transformer. Wire wound in careful coils. Metals, magnetic materials and dielectrics combined in careful ratios, spacings and dimensions. The result: a device with precise parameters—pulse shape, rise/fall times, ripple, backswing, overshoot, life. What sets this one apart? A unique thing—Carad capability. Capability gained in designing and building hundreds of special pulse transformer types to exact specifications. Weights from ounces to hundreds of pounds. Ratings from 10 volts to 500 kv. None of these extremes are considered limits at Carad. For pulse transformers of any type you will find it worth your while to investigate Carad capability.

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AS THEY'RE LONG
BUT
THEY DO HAVE
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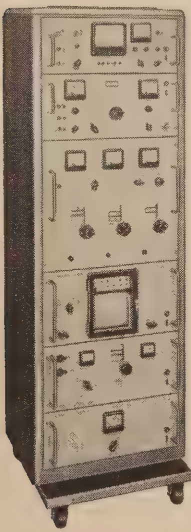
AP 142

MEASUREMENT & COMMUNICATION | **NEWS**

Another Example of ROHDE & SCHWARZ Contribution to Precise Measurement.

PRECISION DECADE FREQUENCY MEASURING SYSTEMS

Generate and measure frequencies from zero to kilomegacycles. Basic component is frequency synthesizer which generates continuously variable frequencies of extreme stability and accuracy derived from a single standard frequency.



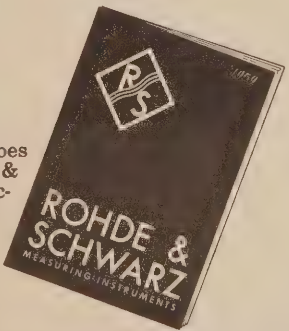
- Fast, direct reading of frequency on three dials calibrated in megacycles, kilocycles and cycles. Vernier reading in millicycles can be added.
- Smallest crystal controlled step 10 cps.
- Suppression of spurious harmonics better than 60 db.
- Accuracy 2×10^{9}/day with Type XSB Standard.
- Short time stability approximately 1×10^{10}.
- System comprises a number of component units which can be combined in various ways in accordance with desired range and applications.

Write for Bulletin DFS.

Write for New Catalog

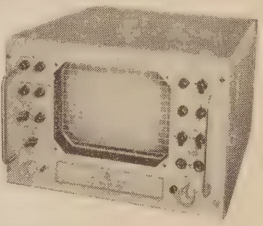
36-page catalog describes complete line of Rohde & Schwarz precision electronic measuring and testing equipment.

Write for your free copy of Catalog-MT.



ROHDE & SCHWARZ
MEASURING INSTRUMENTS

POLYSKOP ELECTRONIC TEST INSTRUMENT FOR TWO AND FOUR TERMINAL NETWORK MEASUREMENTS

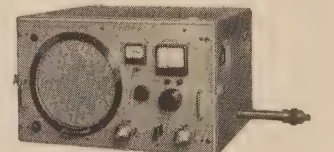


Displays two separate quantities such as impedance and gain as functions of frequency in the form of continuous curves. Frequency range: 500 kc to 400 mc. Instrument contains a sweep signal generator, precision variable attenuator, electronic switch, crystal marker generator and large screen oscilloscope which provides a complete precision measuring system.

Applications include laboratory and production testing of band-pass filters, limiters, all types of amplifiers, television receivers, attenuators, discriminators and coaxial cables.

Write for Bulletin SWOB.

DIAGRAPH



30 to 2400 mc. Plots, instantaneously and accurately by means of a light spot, complex impedances and admittances directly on Smith charts. Eliminates tedious measurements and involved calculations. Instrument can also be used as a phase meter over its frequency range.

Applications: impedance measurements on semi-conductors, antennas, filters, receivers, amplifiers.

Diagraph is available in three models: ZDU covering frequency range 30 mc to 300 mc and ZDU (420) from 30 to 420 mc; ZDD from 300 mc to 2400 mc. Overall accuracy is better than 3% for amplitude and 1.5° for phase angle.

Write for Bulletin Diagraph.

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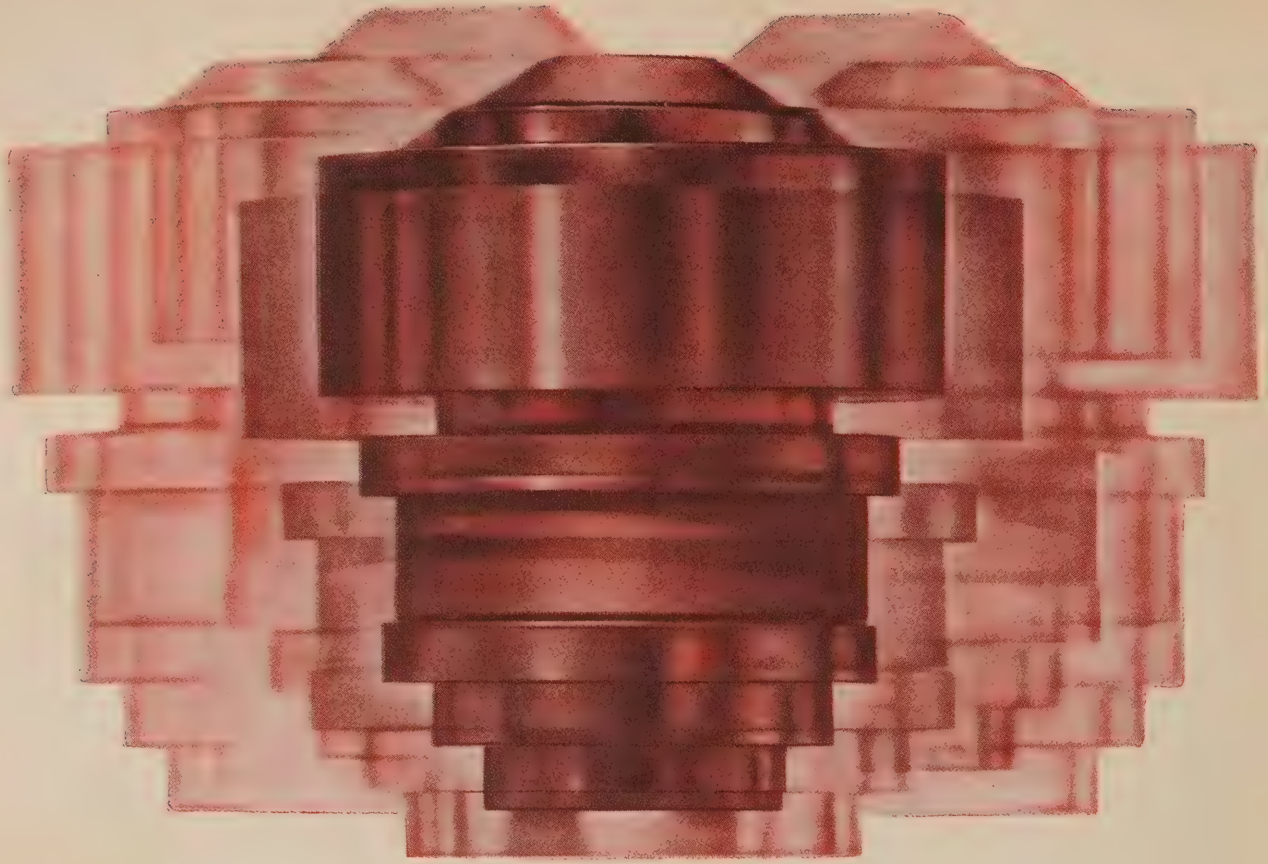
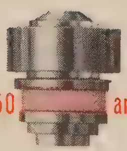


ENGINEERED TO WITHSTAND 20 G VIBRATION

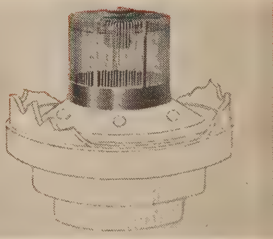


New RCA-7650 and -7651 Ceramic-Metal Beam Power Tubes promise dependable operation even when subjected to vibrational accelerations well over 2

When you're designing equipment for missile use, you can't take chances. You must be *sure* you're using the toughest tubes you can get. That's why the exceptional ruggedness of RCA-7650 and RCA-7651 is so important to you.

These two unique new ceramic-metal beam power tubes will actually withstand 20 g vibrational acceleration without adverse effect. In fact, both types have successfully undergone variable-frequency vibration tests (20-2000 cycles) with peak accelerations of twice that amount! Resistance of these tubes to vibration as well as to shock means dependable operation during the critical moments of launching and after. No wonder missile-equipment designers are so enthusiastic about these new tubes.

Both RCA-7650 and RCA-7651 feature a coaxial electrode structure which makes them adaptable to either coaxial-cylinder or parallel-line circuits. Both utilize RCA's exclusive grid-making technique for precision grid line-up and exceptional structural rigidity. Capsule data on these two forced-air-cooled types are shown in the adjacent chart. Technical bulletins on these types are available from RCA Commercial Engineering, Section D-35-Q, Harrison, N. J. For further information about these tubes and other RCA Ceramic-Metal Power Tubes, contact the RCA Field Representative at our office nearest you.



Type	Operation	Max Plate Volts	Max Plate input Watts	Max Plate Dissipation Watts	Useful CW Power Output Watts		Power G	
					at 400 Mc	at 1215 Mc	at 400 Mc	12
RCA 7650	CW	2500	1250	600	800	450	14 db	

Type	Operation	Max Plate Volts	Max DC Plate Amperes During Pulse with 10 μs duration and duty factor of 0 01	Max Plate Dissipation Watts	Useful Power Output at Peak of Pulse-Watts at 1215 Mc	P 12
RCA 7651	Screen and Plate Pulsed	8000*	9	600	39000	8
	Grid Pulsed	4000	9	600	20000	

*Peak Positive

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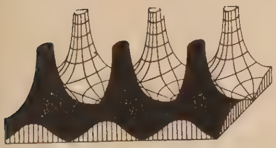
Merchandise Mart Plaza, WHitehall 4-2900; **Los Angeles** 22, Calif., 6355 E. Washington Blvd., RAymond 3-8361

April, 1960
Vol. 48 No. 4
Proceedings of the IRE

Poles and Zeros



Space Electronics: "That which is characterized by extension in all directions," "of or pertaining to an electron or electrons," are Webster's definitions of space and electronics. Modern usage combines the two words, and in their modernity, as a single term, they have taken on a broad and very important scientific meaning. This, April, issue of the PROCEEDINGS reports a comprehensive and detailed definition of the term "space electronics" in its modern connotation.

For many months the public press has been filled with disquieting discussions of the pros and cons of the status of missiles and the entire "space program" of our nation. While discussion rages (and Generals disagree) it is fortunate that the scientist and the engineer move ahead with the task of finding the answers to many perplexing, interesting, and exciting problems.

The treatment of the subject to be found in this volume of the PROCEEDINGS resulted from an idea suggested by former Editor Ryder. The Editorial Board finding merit in the idea asked Conrad H. Hoeppner, Chief Scientist of Radiation Inc., to organize the issue. The wisdom of the Editorial Board's decision is demonstrated by the 53 impressive papers that he has assembled. Mr. Hoeppner is to be congratulated on the excellence of his work, and its results. The cover illustration for this issue was also Mr. Hoeppner's idea; he assisted and guided the preparation of the art work. He has added this chore to his other responsibilities as Editor, and as Chairman of the Professional Group on Space Electronics and Telemetry.

It is reassuring to learn of the extensive progress of research and investigation by the foremost workers in the area of space electronics. This issue marks another milestone in the IRE array of Special Issues.

Headquarters: IRE marks its continuing growth by the acquisition of the building at 984 Fifth Avenue; it is adjacent to and on the north side of its present building, 1 East 79th Street, in New York City. IRE now owns a group of three buildings on the northeast corner of Fifth Avenue and 79th Street. All originally belonged to the family of Irving S. Brokaw, famous 19th century clothier.

The Institute took occupancy of the initial building at 1 East 79th Street in 1946, and acquired the adjoining building at 5 East 79th Street in 1954. As is evident from the Table of IRE Growth, the necessity for additional space in the future becomes self evident. The purchase of 984 Fifth Avenue provides this space. There are no immediate plans for occupying the building, which is presently still in use as a private dwelling.

A study of the statistics in the Table yields some interesting results. At the end of 1953 Headquarters floor space was approximately 0.4 square feet per member. The time had arrived to provide additional space. Again, at the end of 1959 the same floor area per member has been reached and the new building acquired. Assuming a continuation of the efficient use of facilities the building just added should provide adequate floor space until the membership reaches 124,000. The acquisition of the new building thus assures that the rapid growth of IRE activities and services may continue unabated during the coming years. It is startling to discover, however, that if the recent rate of growth is maintained, the figure of 0.4 square feet per member may again be reached as early as 1965. A similar study of the data of the Table gives very roughly the figure of 1.8 square feet of Headquarters per page of publications and would indicate approximately 27,000 pages as the publication output in 1965. The Table would also predict a Headquarters staff of 260 in that year. The figures probably mean nothing in an Institute as dynamic as the IRE, but it's still fun to speculate.

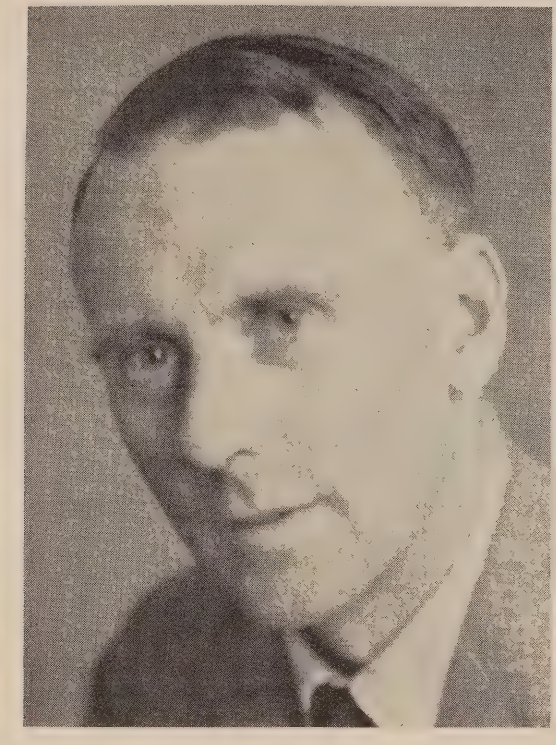
TABLE OF IRE GROWTH

	12/31/45	12/31/53	12/31/59
IRE Membership	15,782	37,134	79,162
PG Members	0	21,797	87,027
IRE Sections	36	71	105
IRE Annual Expenses	$175,000	$1,300,000	$3,300,000
Publication Output (pages)	1,882	8,360	17,968
Headquarters Staff	32	85	170
Headquarters Floor Space (sq. ft.)	15,668	31,293	48,946

The building was purchased with IRE funds which were accumulated gradually over the years under a program of careful financial management. Our thanks go to our astute Treasurer, W. R. G. Baker, and to our Executive Secretary, George Bailey.

Better Paper: Beginning with the February issue, as an experiment, the same type paper has been used in the editorial section as had previously been used in the advertising section only. The principal difference is that the new paper has a glossy finish, providing a noticeable improvement in the reproduction of line drawings and halftones. In addition, the new paper is slightly heavier; thus the ink on one side of the sheet does not show through as much on the other side of the page. The new paper will tend to become more yellow with age, especially if exposed for long periods to sunlight, however, the amount of yellowing that is likely to occur to a bound volume in the library over a fifty year period will not be serious.

Convention Record: Now that the 1960 International Convention has taken its rightful place in IRE history, it is appropriate to issue a reminder that the Convention Record is no longer distributed free of charge. For your convenience a tear out order blank will be found on page 18A of this issue.—F.H., Jr.



J. A. Ratcliffe

Vice President, 1960

J. A. Ratcliffe (M'29–A'32-F'53) was born in Bacup, England, on December 12, 1902. He studied physics at Cambridge University and received the B.A. degree in 1924. He at once started research work, under E. V. Appleton, in the Cavendish Laboratory and assisted him, and M. A. F. Barnett, with their early experiments on radio waves reflected from the ionosphere. Soon afterwards Dr. Appleton left Cambridge and Mr. Ratcliffe continued his ionospheric researches, first alone, and later with a group of research students.

During World War II, he worked with the Telecommunications Research Establishment (T.R.E.) which was concerned with the design and development of Airborne Radar. When the war was over he returned to his radio research at the Cavendish Laboratory. He was joined there by Martin Ryle, who very soon established his own research group of Radio Astronomers.

Mr. Ratcliffe is at present a Fellow of Sidney Sussex College and a Reader in Physics in the University of Cambridge. On October 1, 1960, he will become Director of Radio Research in the Department of Scientific and Industrial Research (D.S.I.R.). He will leave the University and will assume control of the Radio Research Station, Slough, which has had its terms of reference extended to include exploration of the upper atmosphere and outer space by radio and nonradio methods.

His research, and that of his research group, has been concerned almost entirely with the physics of the ionosphere. He has been particularly interested in the magneto-ionic theory (on which he has written a book), ionospheric cross modulation, the diffractive reflection of radio waves from an irregular ionosphere, horizontal movements of irregularities in the ionosphere, the computation of electron distributions in the ionosphere, and theories of the formation of the *F* layers.

Mr. Ratcliffe was made a Fellow of the Royal Society in 1951, and a Commander of the Order of the British Empire (C.B.E.) in 1959. He is at present President of the Physical Society and Vice-Chairman of the Electronics and Communications Section of the Institution of Electrical Engineers. He is Chairman of the British National Committee for Scientific Radio which is responsible for arranging the XIIIth General Assembly of URSI in London in September 1960.

Space Electronics*

CONRAD H. HOEPPNER†, FELLOW, IRE

In lieu of the usual "Scanning the Issue" page, the organizer of this special issue presents below an introduction to the subject of this issue, followed by a brief outline of the contents.—*The Editor.*

The Space Age

A NEW AGE is beginning in the history of mankind—an age in which man is no longer confined to his planet, but is free to travel through the infinite vastness of space. At first he will find this new freedom dangerous and the environment hostile, but as his knowledge increases and he attains mastery of space, the freedom to travel will become safe and the environment friendly. In the new age are limitless possibilities for adventure, exploration, business, pleasure—and war.

The capability to explore space has developed largely through the military efforts of the United States and Russia. While the art of rocketry is old, it has only recently been exploited to the point of space travel. In World War II, German scientists demonstrated a weapon of potentially great effectiveness in the rocket which we know as the V-2. Both the United States and Russia have employed these scientists on their respective rocketry programs and have added their own manpower and other resources to make the programs effective. Peaceful and scientific uses of space probes and satellites have developed through the International Geophysical Year plans and then through the establishment in the United States of the National Aeronautics and Space Administration. The struggle now is to obtain more thrust per pound from chemical fuels and to augment or replace chemical fuels with nuclear and electronic means of propulsion. As these efforts meet more and more success, larger payloads of equipment and men may be taken deeper into space—and returned.

While initial efforts are to obtain more thrust per pound, such a result must be obtained in a manner which will insure reliability and safety. The many hazards of space, among which are dangerous radiation and collision with other objects traveling at high speed, must be surmounted. In order to sustain life, a closed regenerative cycle for producing food, water and oxygen must be perfected and it must function, even in the event that initial supplies are inadvertently destroyed. After survival of a journey in a space vehicle to the moon or another planet, suitable places in which to live must be found, developed and maintained. These places are likely to be underground caves instead of the glamorous "bubbles" so often portrayed by fiction writers. Other unpleasantness and hardships of living on extraterrestrial bodies will develop, but human ingenuity will triumph and eventual success in the colonization of other bodies in space is certain.

Man is a self-sufficient species on earth. There are many portions of his own planet not adequately explored and certainly not colonized. It was not really necessary that he explore and colonize the Americas. He needn't make expeditions to the Poles in order to live amply. It is intrinsic in the nature of man, however, that he is not content with past accomplishment. He must continue to strive for the unattainable and he will not rest even when he has possessed every secret of the universe.

We *will* become space travelers!

We will establish adequate reserves of energy (enough thrust per pound) for travel through space and with the necessary reliability and safety to transport human beings. We will develop protective measures against radiation, collision and other hazards. We will produce suitable regenerative cycles for food, water and oxygen to sustain life reliably. We will provide rapid transportation to man-made satellites, natural satellites, and other planets, and we will develop adequate and even luxurious living accommodations to colonize other extraterrestrial bodies. These accomplishments, however, will demand still greater efforts from the men and nations of the earth. Present efforts fall short *by orders of magnitude.* In the United States, for example, space efforts, measured in dollars, are approximately one quarter of the automobile production. These efforts must increase over one-hundred fold before space travel is common!

Why Explore Space?

Certainly, it has been the military advantage of intercontinental ballistic missiles which has spurred the development of vehicles capable of the exploration of space. Space vehicles, too, have military values both for surveillance and as weapons. Participation in the International Geophysical Year also has led to the uses of rockets and satellites for obtaining scientific data. The physical knowledge of the space surrounding the earth and of the earth itself was increased. Political prestige

---

* Original manuscript received by the IRE, January 11, 1959.

† Radiation Inc., Melbourne, Fla.

has further been a stimulus to the development of space vehicles. The Russian successes have caused the United States to increase its rather minimal space exploration program. Then, of course, there are new territories to "homestead" and new sources of wealth in minerals and raw materials to be discovered. Whether the reasons for space exploration be as listed above, or whether they be for satisfying man's curiosity and his desire to advance, space exploration has begun. It now remains for us to examine how it shall continue.

PLANS FOR SPACE EXPLORATION

Initial exploration of space was with unmanned probes, *viz.:* high-altitude rockets, satellites, and deep-space exploration vehicles. These were supplemented by the terrestrial-based measurements of optical astronomy, radio astronomy, and cosmic particles. These methods will continue, but unmanned space probes will be followed closely by manned vehicles. Such vehicles will travel first around the earth, then to satellite space stations, to the moon, later to other planets, to their moons, and to the planetoids. Combinations of manned and unmanned space probes will also be useful. One plan for visiting the moon calls for the landing of several unmanned alternate vehicles on the moon to insure the safe return of passengers when the manned vehicle finally arrives.

Satellite space stations are a likely development and will serve as refueling stations for further travel, as well as for terrestrial communications. These stations may be both near and far from the earth. A moon base would certainly be a desirable launching point for further space probes and is an ideal base for radio and optical astronomy.

Planetoid bases with their lesser gravities may be extremely valuable for space exploration. They have sufficient volume to provide living quarters and raw materials for construction. Their masses may be used as protection from the radiation hazards as well as particle impacts. Their greatly eccentric but highly predictable orbits make them ideal for further travel to planets.

As to the planets, both Mars and Venus present the possibility of colonization. Mercury may also be habitable. Other planets, because of their high gravity or remote locations, will require much more in the way of propulsive energy and protection for landings or exploration and may be quite unsatisfactory for habitation. The moons of Jupiter and Saturn are more likely targets for exploration and colonization than those planets themselves.

In the exploration of space, the role of electronics is most vital. Electronic measurement and transmission of data are the forefronts of our exploration effort. Recording and analyzing equipment are also largely electronic. Many new equipments and systems are needed for measurements, telemetry, recording and processing. The techniques developed in the past for rocketry must be extended and improved. The need to reduce size, weight and power requirements of the equipment is paramount in the light of our present feeble rocketry capability.

COMMERCIALIZING SPACE

The first uses of satellites probably will be for surveillance. The photographs of the back side of the moon taken by Russian scientists are a typical example. Optical surveillance as well as infrared, radio, and radar surveillance of the earth and other bodies are in demand for military applications, for surveying and for predicting and possibly controlling the weather. A second use of satellites is likely to be the relaying of communications, permitting a vast increase in the number of intra-earth message channels. Multiple station coverage may be controlled for relayed communication as well as for recorded and delayed communication. Satellite usefulness will undoubtedly be extended to include radio and television rebroadcasting with worldwide coverage. This extensive scope of broadcasting will bring about interesting and revolutionary changes in the methods of handling and regulating these facilities. The satellites will also widen our research horizons, as will colonization of the moon and other planets. Astronomical data may be better and more easily obtained on the moon than it is on earth. The ease of providing a vacuum for manufacturing and experimental processes is an obvious advantage. Thermal insulation and the obtaining of low temperatures are radically simplified from conditions on the earth. As a result, it is likely that the space experimental laboratory will differ greatly from its earthly counterpart. Also possible are new manufacturing processes that may produce improved life on earth as well as in space.

FUTURE PROBLEMS

The space age has barely begun, yet almost insurmountable problems have developed. More and more serious problems may be expected in the future.

At first will be the scientific problems. Physical, chemical, biological, and medical laws and limitations will be widened and stretched, possibly beyond our present expectations. On the electronic side, radio-frequency propagation anomalies which are not now suspected will undoubtedly be discovered. The new space environment will cause design and operating changes in practically every branch of electronics.

However, these technical problems may well be obscured by man-made problems unless we formulate regulations and legislation designed to govern the activities of the astronaut. There must be laws common to the many participating countries and additional laws to govern the new encounters in space. International agreements which have been heretofore difficult, if not impossible, to make are necessary to prevent chaos. The social problem of people living in close quarters for long periods of time with mental strains, boredoms, etc., racial or national prejudices, and the possibility of new nations and new governments must be considered. A careful and considered program of space law is a necessity.

In the area of electronics there will be the frequency allocations to prevent interference, and, of course, in radio and television broadcasting, who is to regulate the quality of the programs? As a matter of fact, will the Federal Communications Commission of the United States permit unattended satellite repeater broadcasting stations? What will happen to the "spheres of local interest" which the FCC has fought valiantly over the years to preserve? Installing unattended repeater radio and television broadcast stations all over the United States would be far more economic at the present time than using a repeater satellite. Licenses, however, are not presently granted for this purpose. Also, what is to prevent the unauthorized use of a repeater satellite, a use which may interfere with its normal purpose? It is accessible from every point over half the globe.

Applications of electronics which were not even conceived a year ago are already realities. It is these problems and scientific aspects of space exploration with which the current issue of the PROCEEDINGS OF THE IRE is concerned.

THE APRIL, 1960, SPACE ELECTRONICS ISSUE

Many of the equipments and techniques used in space research and satellite programs are adaptations of those employed in earlier rocket experiments, but on the other hand, some are new. In this latter category is electronic propulsion. Early in the issue this subject is introduced, its merits discussed, and comparisons are made with existing chemical propulsion systems.

In the categories of navigation and guidance, a brief introduction to the solar system is presented and methods of navigation and guidance for interplanetary travel are given. In addition, the use of satellites for navigation of ships, planes and other vehicles on the earth's surface is treated. A theoretical article is presented in which the author develops the thesis that present inertial guidance systems may improve by as much as two orders of magnitude.

Communication from point to point on the earth, from earth to satellite, to interplanetary traveler, and to other planets is considered. In this very broad field of communications, only a few representative and diverse subjects could be included. Tracking and surveillance papers are presented which illustrate a small portion of this field.

Telemetry in space is examined from a number of aspects. As usual, the paramount problem is that of transmitting as much data as possible for as great a distance as possible with a minimum of equipment.

A representative group of papers representing instruments and measurements has been chosen, ranging from those necessary to maintain and direct the vehicle to those used to discover the physical conditions in outer space.

While space electronics is introduced to readers in this issue of the PROCEEDINGS OF THE IRE, the TRANSACTIONS of the Professional Group on Space Electronics and Telemetry will continue to present these subjects to its members. Six basic divisions of the PGSET are active in collecting and disseminating information in the following categories:

1) Telemetry and Remote Control.
2) Space Instrumentation.
3) Space Communications.
4) Space Navigation.
5) Electronic Propulsion in Space.
6) The Effect of Space Environment on Equipment and Living Things, Including Humans.

If any of these subjects is of interest, a cordial invitation is extended to our readers to continue that interest with the PGSET and its TRANSACTIONS.

The NASA Space Sciences Program*

Summary—**This report, prepared in April, 1959, summarizes the objectives of the space sciences program of the U. S. National Aeronautics and Space Administration and the immediate and long-range plans for carrying the program out. The report is divided into several broad areas: atmospheres, ionospheres, energetic particles, electric and magnetic fields, gravitational fields, astronomy, and biosciences. Included in the discussion is a review of present knowledge and existing problems in each of the above areas.**

THE U. S. National Aeronautics and Space Administration is developing a national space sciences program on as broad a basis as possible. In the planning and programming, advantage is being taken of the advice of many specialists and experts in the scientific community. In the conduct of satellite and space probe experiments, broad participation of the scientific community and industry, along with government, is planned, and steps are being taken to secure such participation. The developing program has captured and increased the momentum in space research developed during the International Geophysical Year.

The present status of the national space science program is described in the following sections. For convenience, the subject of research in space has been divided into several broad areas: Atmospheres, Ionospheres, Energetic Particles, Electric and Magnetic Fields, Gravitational Fields, Astronomy, and Biosciences. For each area, the principal scientific objectives are stated, followed by a review of present knowledge and existing problems to be solved. Each section closes with a statement of the long-range program and of the immediate program now under way.

The subdivision used is one of convenience only. Actually, the various areas are related in many complex ways. Investigations of the various interrelationships are a very important part of the search for a better understanding of many puzzling phenomena.

It is recognized that the national space sciences program is subject to continuing review, amplification, and modification as work progresses and scientific data and results are obtained from currently-orbiting space vehicles. Moreover, desired scientific experiments must continuously be matched with the present and future capabilities and availabilities of vehicles, supporting technology, and facilities.

ATMOSPHERES

Objectives

To determine and understand the origins, evolutions, natures, spatial distributions, and dynamical behaviors of the atmospheres of the earth, moon, sun, and planets; and their relations to the medium of interplanetary space. To investigate atmospheric phenomena associated with interactions between photons, energetic particles, fields, and matter. To understand the relations between the earth's upper atmosphere and its surface meteorology. To evaluate atmospheric effects on instrumented and manned space flight.

Present Knowledge

The Earth's Atmosphere: The structure, *i.e.*, temperature, pressure, and density, of the earth's upper atmosphere is partially known from indirect observations and from rocket soundings at New Mexico, Fort Churchill, Canada, in the Arctic, and on the equator. Up to about 110 km altitude, density and pressure both fall off by a factor of roughly 10 for every 10-mile increase in height. At higher altitudes, the rate of decline in density and pressure is markedly slower. Starting from the ground, temperature falls steadily with height until at about 12 km (in temperate latitudes) the temperature reaches a minimum of about −55°C. With increasing altitude, the temperature then rises again to a maximum of about 0°C at between 50 and 60 km. After that, there is a sharp decline in temperature to probably less than −75°C at between 80 and 85 km height. Throughout the *E* and *F* regions of the ionosphere, kinetic temperature rises to 1000°C or more, and perhaps to above 2000°C. The structure parameters vary with both time and geographic position. Pressure, for example, varies by a factor of at least two at 100 km and by a factor of six or more at 200 km. Indications from rocket measurements are that variations by orders of magnitude in pressure and density may be expected at *F*-region altitudes and higher.

The composition of the atmosphere is essentially the same from sea level up to the *E* region at 100 km. Small amounts of ozone are created by solar ultraviolet radiation, the maximum concentration being found at between 25 and 30 km in the daytime. In the *E* region and above, molecular oxygen dissociates to atomic form. Rocket observations at Fort Churchill have shown a marked diffusive separation of argon relative to nitrogen starting at altitudes between 100 and 120 km and increasing into the lower *F* region.

Rocket wind measurements and indirect ground-based observations have indicated fast-moving winds at all levels of the upper atmosphere. Typical speeds are 20 to 50 meters per second between 30 and 120 km, while speeds higher than 100 meters per second have

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* Original manuscript received by the IRE, December 2, 1959. Prepared by the Office of the Asst. Dir. for Space Sciences, Natl. Aeronautics and Space Admin., Washington 25, D. C., April 16, 1959.

been measured. In general, the winds are from the West and strong in winter and from the East and weaker in summer. Marked wind shears have been observed in the *E* region of the ionosphere.

The Sun's Atmosphere: The sun's atmosphere may extend with decreasing density throughout the solar system. At a distance of about 20 solar radii (nearly 0.2 Astronomical Units) the atmosphere is still directly observable by its blurring effects on the radio stars seen through it. Near the earth's orbit, it is estimated that this atmosphere contains several hundred protons per cubic centimeter and has an electron temperature of 250,000°K.

The Moon's Atmosphere: The moon lacks any appreciable atmosphere, although a highly rarefied ionosphere has been indicated by radio astronomical observations.

Planetary Atmospheres: Mercury has no observable atmosphere, and Pluto is too faint for an atmosphere to be detected through the terrestrial atmosphere. Atmospheres have been observed on each of the other planets and on one of Saturn's satellites.

Venus is covered by an extensive atmosphere of which CO_2 is the primary constituent. H_2O has not been identified there although it may be present below the opaque cloud cover which envelops the entire planet. The temperature of the top of the cloud layer has been measured with a thermopile as about 0^0C. Radio-astronomy measurements indicate a temperature of nearly 300°C lower in the atmosphere.

The Martian atmosphere is tenuous compared to the earth's, but H_2O and dust clouds have been observed there. The surface pressure has been estimated at approximately eight per cent of the earth's sea-level atmospheric pressure.

The atmospheres of the major planets (Jupiter, Saturn, Uranus, and Neptune) contain large amounts of H_2 and, presumably, He. Their spectra are dominated by bands of CH_4 and NH_3. The atmospheres of Jupiter and Saturn have a marked banded structure and exhibit differential rotation as does the solar photosphere. In addition, Jupiter shows such puzzling features as the famous red spot, white spots, and lightning-like radio emissions.

Existing Problems

The Earth's Atmosphere: Major problems connected with the earth's atmosphere are exemplified by the following questions, the answers to which are known only partially or not at all.

1) What are the primary sources of energy affecting the high atmosphere, and at what altitude levels are these energies deposited in the atmosphere?

2) What is the average structure of the atmosphere above 80 km over the entire globe; and what are the variations in the structure parameter with respect to season, time of day, geographic location, and solar activity?

3) What is the detailed composition of the atmosphere above 100 km? At what altitude, if any, do the light gases H, H_2, and He predominate over O, N_2, and N?

4) What are the detailed dynamics of the high atmosphere, including the general circulation?

5) What is the relation of the Great Radiation Belt to the heating of the upper atmosphere, and what other sources and sinks of energy are there?

6) What is the energy budget of the low atmosphere and what is its relation to cloud cover and weather systems?

7) What are the relations between the earth's surface meteorology, its upper atmosphere, and solar activity?

8) What is the origin and history of the earth's atmosphere?

The Sun's Atmosphere: Similarly, these questions relate to the sun's atmosphere.

1) What is the composition of the solar atmosphere, particularly at planetary distances?

2) What are the density and temperature of the sun's atmosphere as a function of distance from the sun?

3) How does the sun's atmosphere interact with those of the earth and the other planets?

The Moon's Atmosphere: In this context, two major questions about the moon are raised.

1) Has the moon a trace atmosphere and, if so, what is its composition?

2) If the moon does have a trace atmosphere what are its origins, dynamics, and entrapment near the moon's surface?

Planetary Atmospheres: Finally, the following questions arise concerning the atmospheres of the other planets.

1) What are the major constituents of the planetary atmospheres?

2) What are the surface pressures and densities?

3) What is the altitude variation of their atmospheric structures?

4) What are the atmospheric components that might support earth-type life?

5) Do their atmospheres contain oxidizers available for combustion?

6) Does Venus's atmosphere contain H_2O?

7) Of what does the cloud cover of Venus consist?

8) What causes the apparent changes in transparency of the Martian atmosphere, so-called "blue clearing"?

9) What is the nature and cause of the famous red spot on Jupiter?

10) What is the nature and origin of the rings about Saturn?

11) What are the important dynamic features of these atmospheres?

12) Has Pluto an atmosphere?

Program

Long-Range: Over-all, long-term plans for achieving the above objectives include: 1) instrumented satellite stations around other planets; 2) rocket probes deep into the atmospheres of other planets including soft landings onto the surface with automatic and, eventually, manned recording stations; 3) probes deep into the solar atmosphere; 4) special probes for measuring the density and nature of gas and dust particles in interplanetary space and within comets; and 5) extensive theoretical studies to understand the basic natural phenomena taking place within the atmospheres.

Immediate: Short-range plans include extensive and intensive studies of the structure and composition of the earth's atmosphere from 80 km to several hundred kilometers by direct measurements with sounding rockets and with satellites. Diurnal, latitudinal, and temporal variations in these parameters will be determined and will be correlated with the energy and momentum balances in the earth's upper atmosphere. Models of the earth's atmosphere will be formulated for 1) providing basic data needed in understanding ionospheric, auroral, and other phenomena, 2) providing guidance in the study of the atmospheres of other planets, and 3) providing essential information in the engineering design of the man-in-space launching, guidance, and recovery systems.

Short-range plans for studies up to 80 km include a large number of synoptic rocket flights and several cloud-cover satellites to establish the relationship between surface meteorology and the structure and dynamics of the upper atmosphere. These data are vitally needed to improve weather forecasts and to permit eventual control of certain aspects of the weather.

Immediate steps in the atmospheres research program are: 1) initiation of extensive instrumentation and systems development contracts for measuring atmospheric structure and composition at gas densities of from 1 to 10^{-13} atmospheres; 2) adaptation of currently available atmospheric-structure instruments for an unmanned earth satellite; 3) continuation and improvement of IGY rocket soundings to determine the vital factors in the large variations noted in the IGY atmospheric-structure flights; 4) the development of an inexpensive synoptic meteorological rocket system to permit rapid collection and analysis of data up to 80 km; 5) rocket test flights for proposed satellite instrumentation systems; 6) launching of the remaining Vanguard meteorological satellite to study radiation balance in the earth's atmosphere; 7) completion of the test phases and flight phase of the ABMA radiation balance satellite; and 8) the launching of a 12-foot inflatable sphere to obtain satellite-drag data from which atmospheric densities can be computed.

IONOSPHERES

Objectives

To determine and understand the sources, natures, spatial distributions, and dynamical behaviors of the ionized regions of the solar system, including the ionospheres of the earth, moon, and planets. To investigate ionospheric phenomena resulting from interactions between photons, particles, ions, and magnetic, electrostatic, and electromagnetic fields. To understand relations between solar activity and the terrestrial and other planetary ionospheres, magnetic fields, and upper-atmospheric current systems. To evaluate ionospheric effects on instrumented and manned space flight, including communications.

Present Knowledge

The terrestrial ionosphere, which extends from an altitude of 60 km into interplanetary space, is formed by the ionization of neutral particles, primarily by radiation emitted from the sun. The density of ionization is not uniform. The altitude regions of maximum ion density during daytime are designated D, E, F_1, and F_2. Additional sporadic ionization can occur at various levels, particularly in the E region. Normal D-region ionization extends roughly from 60 to 85 km, with maximum values no greater than a few thousand electrons per cubic centimeter. Average altitudes at which maximum densities in the E, F_1, and F_2 regions occur are 105, 150, and 300 km, corresponding to concentrations of 1.5, 2.5, and 20×10^5 el/cm^3. These values are for a summer day in New Mexico during the period of maximum solar activity. Gradients in the lower E and F_1 regions are roughly 10^4 el/cm^3 per km. Very recent results indicate that the concentration above the F_2 region experiences a very gradual decrease to a value of 10^3 el/cm^3 at a height of 10,000 km.

At night the density of ionization in the D, E, and F_1 regions decreases by at least an order of magnitude. The concentration decreases by less than this factor in the F_2 region, with the result that the nighttime ionosphere shows a single F region predominant with comparatively little ionization below 170 km.

The E-region altitude is relatively insensitive to latitude. However, the F-region height is greatest over the equator and decreases by 100 km at temperate latitudes. Ionospheric irregularities are strongly dependent on geomagnetic latitude, with extremely irregular conditions occurring in the auroral zones. The electron density varies strongly with the solar sun-spot cycle, by as much as one order of magnitude in the F_2 region. The major ionized constituents of the E and F regions are nitric oxide and atomic oxygen, respectively.

The ionosphere makes possible communication over large distances by reflection of frequencies below the critical frequency. Typical values of these critical frequencies are 3 to 4 mc for the E region and 5 to 15 mc for the F region. It should be emphasized that since ionospheric structure is dependent upon diurnal, seasonal, latitude, and solar effects, so are its propagation characteristics. In the lower ionosphere, such phenomena as photoemission, diffusion, and the rectifying action by antennas result in charging space vehicles with potentials up to 20 volts.

Very little is known about the ionospheres of other planets. There are indications of thunderstorms on Jupiter and possibly Saturn and of auroras on Venus.

Existing Problems

Although ionospheric structure is being studied by vertical-incidence radio soundings from surface stations, this method gives results only up to the F-region maximum and provides only integrated effects. Past experience has shown that rocket and satellite measurements of electron density vs actual height are needed to interpret surface ionosphere sounding records correctly, and thus permit their use on a practical synoptic basis.

Since rocket measurements have not been made in sufficient number above the F_2 region and since they have intercepted only an extremely small portion of the ionosphere for small time intervals, the most important unknowns are the details of ionospheric structure, particularly above the F_2 region, as a function of time, season, latitude, and solar and cosmic activity. Collision frequencies and the ionic composition (particularly at low mass numbers) require special investigation.

Present knowledge of ionospheric-propagation characteristics requires extension. Needed are: explanations for anomalous fading effects; polar diagrams of upcoming and downcoming waves and of waves along the magnetoionic ducts; experimental verification of the theories of whistler and Z-mode propagation; the frequencies at which heavy ions influence propagation (hydromagnetic waves); and investigation of the probable existence of very low frequency windows useful for interplanetary communications. Definition of ionospheric structure and propagation characteristics is important to such problems as the calculation of tracking errors in AICBM radars and the choice of communications frequencies.

The interaction between charged particles in the ionosphere with space vehicles is one of the least understood phenomena of space flight. Measurements of vehicle charge, particularly in the Great Radiation Belt and in regions where photoemission effects can become serious (exosphere), are needed to compute possible electrical drag and missile-trajectory errors.

Propagation characteristics of the exosphere and the intensity and nature of cosmic noise need investigation, particularly in the frequency range which is most affected by the ionosphere. These data are important to radio-astronomy observations from space vehicles.

Since so little is known about other planetary ionospheres, discovery and survey-type investigations of them are needed first. Then their structure and propagation characteristics also will need to be studied.

Program

Long-Range: The over-all program will exploit current techniques for determining the terrestrial ionospheric structure, its propagation characteristics, and its influence on space flight, by observation from below, within, and above. New techniques for evaluating the least known parameters will be developed. All of the applicable methods will then be used for the study of other planetary ionospheres. Eventually, propagation sounding stations may be established on the surface of the moon. All the data will then be applied to understand the interrelations between solar activity, magnetic fields, the aurora, the Great Radiation Belt, and other phenomena.

Immediate: The immediate program is concerned with obtaining electron-density profiles at altitudes above the F_2 layer by propagation experiments in sounding rockets. Then, latitude and temporal variations of this parameter will be obtained by use of a satellite beacon. Topside sounders in satellites will be used for synoptic studies of electron density in the outer ionosphere. This technique promises less ambiguity than that obtained from satellite beacons. Present knowledge of electromagnetic propagation will be extended by the inclusion of VLF receivers in polar-orbiting satellites and space probes. Ion-spectrum studies will be extended to lower mass numbers and higher altitudes by the inclusion of RF mass spectrometers in space probes and satellites. Direct measurements using devices such as antenna probes, ion probes, and electric field meters will be made in rockets and satellites, to define more precisely ionospheric structure and to study the interaction between the ionosphere and space vehicles.

ENERGETIC PARTICLES

Objectives

To determine and understand the origins, natures, motions, spatial distributions, and temporal variations of particles having energies appreciably greater than thermal. To understand their relation to the origin of the universe. To understand interactions between such particles, fields, photons, and matter. To evaluate possible hazards to life and other effects of energetic particles and photons on instrumented and manned space exploration.

Present Knowledge

Cosmic rays are an important constituent of the energetic charged particles which are known to be present in space. It is now certain that cosmic rays consist primarily of high-energy hydrogen nuclei, plus a small percentage of energetic nuclei of heavier atoms. The heavier cosmic rays are largely energetic helium nuclei but include masses up to that of iron. It has been determined that the cosmic-ray energies cover at least the range from a few billion to a billion billion electron volts. Over this energy range the spectrum is such that the cosmic-ray intensity falls rapidly with increasing energy. Because of this spread of individual particle energies, and because of the magnetic field of the earth, fewer cosmic rays strike the earth's upper atmosphere at the equator than at higher latitudes.

On striking the atmosphere, the cosmic rays produce many secondary particles including electrons, many types of mesons, and fragments of atomic nuclei. Most of these secondaries are absorbed by the atmosphere, but a few reach the earth and some scatter back out of the atmosphere. The intensity of these secondary particles just above the atmosphere is comparable with the cosmic-ray intensity but decreases as the distance above the atmosphere increases. The cosmic ray intensity is not a constant but varies with the sun spot cycle and with magnetic storms and solar flares.

Another group of energetic particles in space comprises the particles which produce auroras. These particle streams contain electrons having energies over at least the range from a few hundred to a few thousand electron volts. Also present are hydrogen nuclei having energies over about the same range as the electrons. On striking the atmosphere, these particles ionize and excite the air atoms producing the light we see as auroras.

A third class of energetic particles known to exist in space comprises the Great Radiation Belt. These particles are in a belt surrounding the earth at latitudes less than 70° and at altitudes between about 600 and 30,000 miles. The intensity of the radiation in the belt is thousands of times that of the cosmic rays. It seems clear that the radiation belt is the immediate source of the auroral particles.

Existing Problems

Among cosmic-ray problems, important phenomena to investigate are: The sources of the primary cosmic rays, the processes by which the particles obtain their high energies, their distribution in space, their variations in intensity and composition with time, their energy spectrum particularly at lower energies, their interrelations with the auroral and radiation belt particles, their effects on both animate and inanimate objects, and their detailed composition including the possible presence of antimatter.

In the field of auroral particles, the following are unknown: The origin and acceleration mechanisms of these particles, their presence or absence in space and near other planets, their rapid variations in intensity and spatial distribution, their detailed composition, and their relations with cosmic rays, radiation belt particles, magnetic fields, the sun, the ionosphere, and with upper-atmosphere processes.

Among the unknowns associated with the Great Radiation Belt particles are: The composition and energy of the particles, their origins, their lifetime, their spatial extent, their possible variations in composition and intensity, their effects on animate and inanimate objects, and their relations to cosmic rays, auroral particles, magnetic fields, the sun, and upper-atmosphere processes.

Program

Long-Range: In situ measurements using deep space probes will be made from the close proximity of the sun to the limits of the solar system. Extensive measurements in the vicinity of the planets, especially the earth, will be made to determine the interaction of the energetic particles with the atmospheres and fields of these bodies. These measurements will require satellite orbits around the earth, the moon, and other planets. The establishment of an observatory on the surface of the moon or on some other planet might be necessary, depending on the data previously acquired by artificial satellites.

Immediate: In the near future, the measurements of energetic particles will be pursued with satellites and rockets in the vicinity of the earth and with interplanetary probes. These measurements will be aimed at determining the interactions of these particles with the earth's atmosphere and field, their interactions with interplanetary fields, the types and energies of these particles, their spatial distribution, and the origin of the energetic particles.

The immediate program includes, specifically, measurements of 1) the cosmic-ray intensity in interplanetary space; 2) time and latitude cosmic-ray intensity variations; 3) the composition and spatial extent of the Great Radiation Belt; 4) the cosmic-ray energy and charge spectrum; and 5) the nature of the particles producing auroras.

ELECTRIC AND MAGNETIC FIELDS

Objectives

To determine and understand the origins, natures, methods of propagation, spatial distributions, and temporal variations of magnetic and electric fields throughout the universe. To understand interactions between these fields and matter in space, and the influence of existing fields on solar and planetary atmospheres. To use these fields in the investigation of the internal constitution of astronomical bodies. To evaluate their effects and interactions on instrumented and manned space exploration.

Present Knowledge

The earth's main magnetic field is approximately that of a dipole located at the earth's center but tilted at an angle of 11 degrees with respect to the earth's axis. The strength, orientation, and uniformity of the main field varies slowly with time. This is called *secular variation.* The field at the earth's surface is also geographically irregular because of differences in the geology of the earth's crust. These irregularities are called *anomalies.* On a time scale of months rather than years, the above features appear constant at a given location. However, using a time scale of days, hours, or minutes, a sensitive instrument shows that the field is practically never constant at any location on the earth's surface. These variations are usually classified as: *diurnal*—the variations that occur in 24-hour cycles and appear similar from day to day; *magnetic disturbances*—large variations that are not a daily event, in which the field changes are often highly irregular for periods of several or more hours over either small or large areas of the earth's surface; *magnetic storms*—large variations which occur more or less simultaneously over the entire surface of the earth; *sudden commencements or impulses*—abrupt changes in the magnetic field which sometimes precede magnetic storms; *pulsations*—sinusoidal oscillations of the magnetic field, with wave periods ranging from fractions of a second to five minutes and frequently persisting for one or more hours and sometimes as long as a half a day. The magnitude and frequency of occurrence of these variations are functions of geomagnetic latitude. The largest diurnal variation is observed at the magnetic equator. The largest disturbance and storm variations occur in the auroral zones in association with visible auroras. Sudden commencements and impulses tend to be world-wide. Pulsations are most prominent in high latitudes and reach their greatest magnitude in the auroral zones.

From the study of surface measurements and from theory, it is believed that these variations are caused primarily by electric currents in and above the ionosphere. The currents are attributed to the dynamo action of tides and winds in the ionized gas and to the influx of particles from the sun. Recent thinking on hydromagnetic phenomena has led some theorists to believe that interactions between the outer portions of the earth's field and the motion of solar gas clouds also contribute to the variations. It has not, however, been possible to prove any theory or establish an understanding of the phenomena solely from surface measurements. Here lies the importance of direct measurements from space vehicles.

Sensitive magnetometers have been successfully flown into and through the *E* region. These flights demonstrate the existence of electric currents in the lower ionosphere at the magnetic equator and in the auroral zones and showed the expected decrease in field intensity with altitude. More than anything else, they show the need for more measurements.

The magnetic fields of the sun and other stars have been studied intensively, but it cannot be said that there is concrete knowledge of their strength and form. Indirect measurements and theories permit a wide range of possibilities. Galactic field intensities have been estimated from theoretical considerations and the study of light polarization; values between 10^{-3} and 10^{-6} gauss have resulted. Theoretical studies of planetary fields (other than the earth's) apparently do not exist, and methods of indirect measurement have not been found.

An electric field exists between the earth and its ionosphere, corresponding to an average potential difference of 290,000 volts. There is no direct knowledge of the existence of magnitude of electric fields outside the ionosphere. Theories of the origins and accelerations of auroral particles and cosmic rays allow a wide range of possibilities for interplanetary electric-field values.

Existing Problems

The unknowns of most urgent interest are usually those which are most apparent. The most apparent unknowns in magnetic field phenomena are the sources of field variations and the relationships between these variations and other solar-terrestrial phenomena. It is known that some variation is due to ionospheric currents; but the existence, location, and strength of possible electric currents above the ionosphere are not known even though their existence appears probable. Strictly speaking, the cause of ionospheric currents is not known; and even less is known about probable causes for currents above the ionosphere.

The form of the earth's main field is known, at least approximately, close to the earth; but at distances of 5 to 15 earth radii, where the field is most effective in guiding solar particles, radical departures from prediction can be expected. The field may expand and contract in response to motions of solar and interplanetary gas clouds. These distortions may in turn propagate as hydromagnetic waves down to the ionosphere and even to the earth's surface. The possibilities can only be considered speculative until field measurements are made in the outer reaches of the earth's field.

At some distance, the earth's field will blend with interplanetary and/or interstellar fields. Estimates of interplanetary fields range from 10^{-3} to 10^{-6} gauss. The strength and orientation of these fields is especially important to the understanding of how solar particles reach the earth.

Theories concerning magnetic fields on other planets are practically nonexistent. One reason for this scientific void is probably the lack of understanding of why the earth has a magnetic field. It is generally thought that the earth's main field is due to dynamo currents in the liquid core, but the form and cause of these currents is still an open question which may be related to the initial formation of the earth. This lack of understanding is, however, one of the principal reasons for obtaining measurements of the fields of other planets which formed under different conditions and have a different composition. Similar thoughts suggest that knowledge of the moon's magnetic field would be a major step toward determining how it formed as an earth satellite.

Direct measurements of the electric fields exterior to the earth's ionosphere and in interplanetary space are important to the eventual understanding of how cosmic rays and auroral particles are accelerated and from whence they come.

Program

Long-Range: Results from satellites, probes, and rockets to be flown in 1959 will be an important factor in determining the long-range program for studying the earth's fields. One can, however, anticipate that an important item will be establishing an earth satellite observatory which will include instruments for measuring particle flux and solar radiations as well as magnetic and electric field instruments such that direct correlations can be made between the various phenomena. Also rocket soundings into the ionosphere will continue to be used to study details of ionospheric currents more thoroughly.

The fields of the moon, Mars, and Venus will first be measured from probes making close approaches and eventually from packages landing and serving as observatories.

Probes will be shot at the sun to obtain solar field measurements as close to the sun as feasible.

In all measurements, except the rocket soundings, the experimental intent will be to obtain both the absolute magnitude and the direction of the magnetic field measured. It will be more difficult to separate the ambient electric field from that caused by an electric charge on the space craft.

Theoretical analyses and correlations between electric and magnetic field phenomena and other phenomena will be an integral part of the program.

Immediate: The short-range magnetic-field program includes:

1) a number of small sounding rockets with proton magnetometers for studying ionospheric currents,
2) two sounding rockets primarily for flight testing of newly-developed Rb-vapor magnetometers and for information on radiation belt currents,
3) a space probe to the moon with a Rb-vapor magnetometer for measuring electric currents and the form of the earth's field at great distances, interplanetary fields, and the moon's magnetic field.

The program also includes instrument development —the most significant being the development of Rb-vapor magnetometers by Varian Associates. It is also anticipated that simpler magnetometers which can detect only the existence of a perceptible field will be placed in several rockets and space vehicles as secondary experiments.

GRAVITATIONAL FIELDS

Objectives

To determine and understand the origins, natures, methods of propagation, spatial distributions, temporal variations, and effects of gravitational fields throughout the universe. To determine and understand the external form and internal constitution of the earth, planets, and stars. To determine and understand the relations between gravitational and electromagnetic fields. To evaluate effects of gravitational fields of different magnitudes, including weightlessness, on instrumented and manned space exploration.

Present Knowledge

At the present time, the best theory of the nature of gravitation is Einstein's general theory of relativity, which asserts that the force which we recognize as gravity results from a distortion of space-time. An essential part of this theory is the idea that mass as determined by gravitation will be found to be proportionate to mass as determined by inertia. Other theories have been proposed, especially by George D. Birkhoff.

There are three tests of the general theory of relativity. The first of these is the motion of the perihelion of Mercury, which amounts to 43 seconds of arc per year, agreeing quantitatively with Einstein's prediction. The second is the bending of light in the sun's gravitational field. It has been measured numerous times, and the results have generally been found to agree with Einstein's predictions; but, in view of the smallness of the effect (only 1.75 seconds of arc), there is still room for reasonable doubt about the confirmation.

The third effect is the shift of light toward red wavelengths in a strong gravitational field. This is doubtfully observed in the sun, where it is confused by mass motions of gases. A red shift is observed in some white-dwarf stars, but even there it cannot be said unequivocally that this is not an effect of mass motion.

It is further believed that the force of gravity is proportional to the density of matter in the universe. Since the universe is expanding, this means that changes of the order of one part in ten billion per year ought to exist in the force of gravitation.

With respect to the gravitational field of the earth, this problem would be solved fully if we knew all the harmonics into which the field can be subdivided. There is one zero harmonic which amounts to the product of the gravitational constant by the mass of the earth, and which has at the present time the value of 3.9868 with an uncertainty amounting to one part in 100,000. There are three possible first harmonics which arise from the displacement of the center of the earth from the center of our present coordinate system. This displacement is believed to amount, at the present time, to no more than 100 meters. There are five second-degree harmonics, of which one harmonic of zero order is intimately related to the flattening of the earth and has been measured with great precision from the motion of the node of 1958 Beta 2 (Vanguard I). Coefficients so obtained correspond to a flattening of 1/298.3. Two of the remaining four are necessarily zero; and the other two have been doubtfully evaluated with an amplitude of about 4 mgals.

Of the seven third-degree harmonics, the zonal harmonic of zero order has very recently been measured, and appears to have a value of 5.6 mgals at the surface of the earth. The other six have been estimated crudely from gravity data. An estimate of 5 mgals has been made for the fourth zonal harmonic. It is known that the size of these harmonics is proportional to the stresses at the interior of the earth roughly at the rate of 1 mgal to 10 kg per square centimeter.

In the case of Mars, the zero harmonic (the mass) is 0.1076 that of the earth. Nothing is known with respect to first harmonics. The second harmonic is determined from the flattening which is found to be 1/192 from the satellite motions, and 1/77 from visual observation. Masses and flattenings for Jupiter, Saturn, Uranus and Neptune are available in the same way, but no higher harmonics are known for any of these planets.

The sun's mass is accurately determined by the motions of the planets. Nothing is known about any other higher harmonics.

Measurements of various double stars yield masses which are found to fall into the range of from one tenth to fifty times the solar mass. The flattening, which ranges from zero up to the limit of instability, is known for a few eclipsing binary stars.

The gravitational field of the galaxy as a whole has been deduced from the rate of galactic rotation. It is found to be equivalent to several hundred billion solar masses. The gradient of the galactic field which measures the flattening of the galaxy has also been determined from the gradient of galactic rotation near the sun.

The nature of the intergalactic gravitational field is at present completely unknown; it is not even certain that a replusion does not exist at sufficiently great distances.

Existing Problems

With respect to the fundamental nature of gravitation, the principal problem is to find some peculiarity of the law which would serve to control the formulation of satisfactory theories. Such a peculiarity might consist, for example, in a small deviation from strict equality of gravitational and inertial mass, or in a velocity of propagation, or in something in the nature of a shielding such as is observed with magnetism. Any one of these effects would give us a clue to the best direction to look for a more fundamental understanding.

Within the framework of the Newtonian Law, the classic problem is that of the long-time stability of a system such as the solar system. The problem may be formulated in this way: As we think of time of the order of 10^9 years, do the orbital planes of the planets tend to approach one another? Do the eccentricities tend to decrease? If so, then, of course, we understand the architecture of our present solar system; if not, then we have an important clue which can someday be used to discover how it was initially formed. The problem of the stability of the solar system has engaged some of the best mathematicians since the days of Lagrange and Laplace, who found that stability could be guaranteed for times of the order of 10^8 years.

With respect to the gravitational fields of the planets, one problem is that of the presence of iron cores in the planets. At the present time, the large density (approximately 5) found for Mercury indicates a large iron core. It is hard to put this in an orderly relation with the density of Mars (about 3.9) and the moon (about 3.3). In particular, if correct, this density means that the iron core found in some planets cannot represent a pressure modification of ordinary silicate rock. A second test of the pressure modification idea is furnished by the density of Venus, which is just at the critical level. In both cases, it appears possible that further observational data would reverse the conclusions which have been drawn.

The gravitational field of the earth is closely related to a series of interesting problems. In the first place, the zero harmonic is essential for the study of space trajectories. Next, the internal constitution of the earth manifests itself through variations in the higher harmonics. In particular, a state of hydrostatic equilibrium in the interior of the earth demands the value of 1/297.3 for the flattening of the earth. The discrepancy between this and the observed value of 1/298.3 is a major problem in determining the structure of the earth. If the discrepancy is due to mechanical strength in the interior, then it may be related to the observed large values of some of the higher harmonics.

At the present time, two independent and contradictory theories have been offered for the inner structure of the earth and for the formation of mountain ranges. The first of these, which we might call the plastic theory, envisions a viscous interior in which slow convection currents of a few centimeters per year exist, and mountain ranges, such as those around the Pacific, are formed as the result of drag on the underside of the continents. The other theory, which we may call a crystalline theory, considers that the earth is slowly contracting as it cools, and attributes the formation of mountains to crumpling. At the surface of the earth, the problem of verifying or disproving the "basic hypothesis of geodesy," namely that the product of gravity anomalies in milligals times areas in square kilometers does not exceed 30 for any extensive patches, is one of the most important that can be set up.

Program

Long-Range: For the study of the fundamental nature of the gravitational field, two avenues are opened by our ability to launch satellites and space probes. The first of these is the ability to try experiments on a scale of hundreds and thousands of kilometers by probing the fields of planetary masses with bodies capable of being accurately observed. This is significant because gravitational fields, except that of the earth, are almost unmeasurable in laboratory-scale experiments. The second avenue results from the fact that the periods of artificial satellites are so much shorter than those of the moon and other natural satellites that we can observe in a few years a number of revolutions corresponding to thousands of years for natural satellites. By the first avenue, we hope to find the links which must exist between the theory of the electromagnetic field and the gravitational field. It is planned, in particular, to test the equality of gravitational and inertial masses by experiments in space on a colossal scale, which are a repetition of the experiment of Galileo in the Leaning Tower of Pisa. An attempt will be made to devise experiments which will reveal the velocity of propagation of gravitation, if any.

It is planned to determine the masses of the inner planets by direct observation of probes passing near them or possibly around them. These probes will, at the same time, help to determine the value of the astronomical unit, the fundamental meter-stick of the solar system.

It is planned to test the hypothesis that gravitational attraction depends on the average density of matter in the universe and that, therefore, it is slowly weakening as the universe expands. For this purpose, an atomic clock on the ground can be compared with a gravitational clock of some kind. A proposal for a gravitational clock consisting, in effect, of a high satellite with a very well measured orbit is being studied.

It is planned to employ moon probes to obtain improved values for the over-all mass of the moon and for the moments of inertia about its three principal axes. A determination of the strength of the materials in the moon's interior will be attempted from this information.

It is planned to measure the mass of Venus and of Mercury in order to test Bullen's idea about the nature of the cores of the planets.

Using the second avenue, it is planned to observe the motions of close satellites of the earth over a long period and to make a precise comparison with theory, searching for systematic trends in the inclination and the eccentricity, which might shed light on the history of the solar system.

Immediate: There are several phases of the short-term gravitational field program:

1) Studies are now being made on existing satellites with the object of determining the low harmonics of the earth's field from tracking data.

2) Preparations are made for equipment for a special geodetic satellite which will be capable of refining the observations on the harmonics, and of determining intercontinental distances with high precision. It will clearly be possible to carry the study of the form of the geoid much further than has been possible to date.

The information developed in 1) and 2) above will be applied to the question of the basic hypothesis of geodesy. This hypothesis, as formulated by some theorists, is in essence that the low harmonics of the earth's gravitational field have amplitudes of a meter or so. The hypothesis is not universally accepted; other theorists consider that the amplitudes are of the order of scores of meters. A decision between these two hypotheses is important because Heiskanen, in particular, proposes extensive work based on Stokes' theorem—work which is warranted only if the basic hypothesis is satisfied. This information will also be used in an attempt to evaluate hypotheses of convection in the mantle. These hypotheses seem to go with the ideas of the first-mentioned school of theorists, and it may be possible to decide between these hypotheses and the alternative contraction hypotheses on the basis of our information.

3) It is planned to put in orbit a satellite carrying a very precise clock in order to test a theory of Einstein which predicts a change in the clock's speed with a change in the strength of the earth's gravitational potential. If successful, this would constitute a new test of the general theory of relativity, and so improve our understanding of the nature of the earth's gravitational field.

ASTRONOMY

Objectives

To determine the spatial distributions of matter and energy over the entire universe, and to understand their cosmological origins, evolutions, and destinies. To observe from above the earth's atmosphere the spectral distributions of energy radiated from objects in the solar system, in this and other galaxies, and in the intervening space, with emphasis on observations that are prevented or compromised by the absorption, background emission and refraction of the earth's atmosphere. To determine and understand the structure and the surface features of the planets. To determine the effects of meteors, radiations, and other astronomical influences on instrumented and manned space exploration.

Present Knowledge

The field of astronomy may be divided broadly into five categories: 1) the solar system, 2) the stars, 3) interstellar matter, 4) the characteristics of stellar aggregates, such as clusters and galaxies, 5) the history and evolution of the universe and its various components.

The Solar System: The dark bodies orbiting around the sun may be classified as planets, satellites, minor planets or asteroids, and comets. The nine planets, including the earth, differ primarily in size and in temperature. The smallest ones, such as Mercury, have too little gravitation to retain any atmosphere, while the larger planets, such as Jupiter and Saturn, have extremely dense atmospheres. Those planets closest to the sun have, of course, quite high temperatures, whereas the most distant planets are very cold. With respect to the amount of atmosphere and to temperature, Venus, Earth and Mars are intermediate, and these three planets are considered to be the only ones that might naturally support any form of life. Earth may be the only planet on which conditions are so ideal as to favor the evolution of intelligent life. Asteroids and most of the satellites of planets are small bodies, ranging from dust particles to boulders a few hundred miles across. The comets are loose agglomerations of rock and gas that spend most of their time in the far reaches of the solar system and approach the sun at infrequent intervals. The asteroids and comets are probably the debris left over from the formation of the planets some five billion years ago.

The Stars

It is now known that the stars are gaseous bodies composed of about 75 per cent hydrogen by weight, 25 per cent helium, and traces of the remaining elements. Most stars derive their energy from the conversion of hydrogen into helium deep in the stellar interior where temperatures and pressures are extremely high. This energy is transferred to the outer layers of the star by radiation and convection; there the emerging light is affected by the constituents of the stellar atmosphere, producing the observable stellar spectrum. This spectrum, together with independent information concerning the star's luminosity and mass, is the basic datum from which all knowledge of the star's structure must be deduced. A significant stellar characteristic is the fairly well defined correlation between surface temperature, as evidenced by a star's spectrum or color, and intrinsic luminosity. The form of this temperature-luminosity diagram has yielded much information concerning the nature of stellar atmospheres. From the study of spectra it is found that the chemical constituents are approximately constant from star to star; however, other parameters vary widely. Surface temperatures range from 1500°K to more than 50,000°K. Stellar diameters vary from less than 0.01 to more than 500 times that of the sun; masses range from 0.1 to 50 solar masses; and intrinsic luminosities vary by a factor of a hundred million. The outer layers of a star are far from being in equilibrium. This is obvious in the case of the sun, where sunspots and their accompanying magnetic fields, intense hot spots called flares, and eruptions from the surface, called prominences, indicate large-scale thermal and magnetic instabilities. The cause of these instabilities and, more basically, the reason for their twenty-two year periodic variation are not yet understood. Other stars show even more striking examples of instability; stars which pulsate with periods of days or even hours; others which exhibit large, highly-variable magnetic fields; and, finally, the novae and super-novae, which are subject to catastrophic explosions.

Interstellar Matter: The material between the stars has a composition similar to the stellar composition, in the form of individual atoms and radicals and small dust particles, or grains. The space density of this material is a few atoms per cubic centimeter and except near hot stars it has a kinetic temperature of about 100°K. In spite of the low density, the total mass of interstellar matter in the Milky Way is approximately equal to the total stellar mass. This material has a profound effect on stellar observations because its scattering reduces the intensity of starlight passing through it, and because it superposes interstellar absorption lines on stellar spectra. In addition, the material has a marked tendency to occur in clouds near hot, luminous stars, which themselves are often found in clusters. In these cases, the interstellar clouds are illuminated and become visible as reflection nebulae. If the nearby stars are hot enough to excite the gas, an emission nebula results, emitting energy primarily in the lines of hydrogen and of some of the trace constituents. In these nebular complexes, the density may be as high as a thousand atoms per cubic centimeter, and the kinetic temperature is usually about 10,000°K. Knowledge of the interstellar medium has increased rapidly since the development of radio astronomy. Radio-frequency emission has been detected from the neutral hydrogen in the insterstellar gas, and has proved to be a valuable tool in probing distant parts of the galaxy. Thermal RF radiation has been observed from emission nebulae, and RF synchrotron radiation has been measured from nebular remnants of supernovae explosions. The polarization of starlight has indicated the existence of magnetic fields in the interstellar medium which may play an important role in the production of cosmic rays.

Star Clusters and Galaxies: Stars tend to occur in multiple systems of two to six stars and in clusters of tens to many thousands. The study of such clusters has been valuable because the members presumably have common origins and histories and thus present homogeneous populations suitable for statistical analysis. On a larger scale, stars are clustered into galaxies containing billions of members. In appearance, these galaxies range from the smaller systems, which are spherical, ellipsoidal or irregular, and composed of fainter stars and little interstellar gas, up to the massive, highly-flattened spiral galaxies which show a great deal of complex structure. Our galaxy, the Milky Way, is an example of the latter type. It consists of a central spheroidal nucleus of stars, surrounded by a round stellar sheet, quite thin compared to its diameter. Within this sheet, the galactic plane, the brightest stars, and most of the interstellar material are concentrated into spiral arms. The sun is within such an arm. However, in addition to these stars, there is a second group of stars having different temperature-luminosity and velocity characteristics which are spherically distributed about the galactic nucleus. These so-called Population II stars are quite similar to the stellar populations of the smaller elliptical galaxies. It appears that spiral structure with its associated interstellar material and bright stars may be a superficial and rather recent phenomenon superposed on an older and more fundamental stellar population of which all galaxies are composed.

Stellar Evolution: With the possibility in mind that there are stars with different ages and histories, the differences between the temperature-luminosity diagrams of different groups of stars, and especially of different star clusters, may be interpreted as being due to age and evolutionary differences as well as to small variations in chemical composition. The presently available evidence points to the following picture of galactic and stellar evolution. The original material of the universe coalesced into discrete globs or proto-galaxies and, in turn, stars and star clusters condensed out of these globs. After the initial period of star formation, those galaxies which had no excess material, or which lost their excess material through intergalaxy collisions, evolved into the elliptical galaxies. In the remainder, the excess material collapsed into flat sheets in which star formation has continued at a slower pace up to the present time. Star formation can occur when a local inhomogeneity in a dense interstellar nebula becomes large enough and dense enough to contract due to self-gravitation. The interior pressure and temperature eventually becomes sufficiently high to support thermonuclear reactions and the gas becomes self-luminous, after which radiation pressure prevents the accumulation of appreciable interstellar material. The size and luminosity of the new star are determined by the amount of material accumulated before energy production begins. Multiple star formation from a single cloud is common. In some cases, the nebular material remaining around a new star condenses into planets. Single stars not surrounded by planetary systems are probably rare. Stars consume themselves by an ever accelerating process of converting hydrogen into helium until the hydrogen is exhausted. At this point the internal support of the star due to radiation pressure is removed and the main body collapses, while a tenuous outer atmosphere expands to tremendous proportions to preserve dynamic balance. The main body contracts until the central temperature and pressure become high enough to support the conversion of helium into heavier elements with an accompanying release of energy. During this evolution, the star may pass through phases of dynamic instability where pulsation occurs. Eventually the star has no more energy resources left to support its mass and an implosion occurs, producing a nova. The post-nova stellar core may then settle down into an extremely dense sub-luminous white dwarf star until it goes out completely.

Current Problems

The Sun: The sun is the only star on which we can study small regions of the surface and atmosphere. For this reason, and because solar radiation profoundly affects the physical conditions in the earth's atmosphere, the sun is an object of prime importance for detailed study. To gain a better physical picture of the conditions in the undisturbed sun, more accurate measurements are needed of the solar constant and of the energy distribution in the entire solar spectrum, not just in the region observable from the surface of the earth. Also, particularly because of its effect on terrestrial conditions, a long-term study of the disturbed sun in all wavelengths, especially in very short optical wavelengths and in very long radio wavelengths, is of great importance.

The causes and nature of the phenomena occurring in the solar atmosphere and their effects on physical conditions in interplanetary space are of vital importance in the climatology of the planets. Some basic problems involve the propagation of disturbances through the solar atmosphere, the role of convective transport of energy in this atmosphere and the origin, support and heating of the chromosphere and corona.

The Solar System: There are still many pertinent questions concerning the physical characteristics of the planets and the other constituents of interplanetary space. More information is required on the percentage concentration of oxygen, water vapor, and other important gases in planetary atmospheres; the physical properties of the planetary surfaces; and the structure of planetary interiors. Since the maximum intensity of the thermal radiation from the planets occurs in the infrared, it is obvious that studies in these wavelengths are important for deriving the physical characteristics of the planetary surfaces. The important band spectra from planetary atmospheres tend to occur in the infrared also. In addition, even those absorptions in the region of the spectrum accessible from the earth's surface are partially obscured by similar molecules in the terrestrial atmosphere. Finally, the information needed on the structure of planetary interiors can best be derived by studying the effects of these planets on nearby satellites. Artificial satellites which should eventually prove particularly useful for this purpose.

An interesting question is that of the existence of a permanent interplanetary gas. If this exists, is it primarily the interstellar gas through which our solar system is moving or is it matter ejected from the sun or part of the solar atmosphere? The existence of such a nebula would provide a laboratory for studying general nebular properties, and for studying at first hand a gaseous nebula surrounding a star. In addition, the existence of a solar nebula may also limit our study of nebulae elsewhere in the stellar system.

Stellar Physics: More accurate information is needed on fundamental quantities such as stellar masses, radii, and luminosities. For stars much hotter or much cooler than the sun, the luminosities must be extrapolated from the very small spectral region accessible from the surface of the earth to the regions which contain the predominant energy output of these objects. In the field of stellar atmospheres, more information is needed on the relative importance of radiative transfer as compared to the transfer of energy by mass motion, and on the origin and effects of stellar rotation and magnetic fields. Important information on these problems is provided by the relative energy output in widely separated regions of the stellar spectrum. Our current knowledge of stellar composition, structure, and evolutionary processes depends upon spectroscopic observations in a relatively limited region of the spectrum. It is obviously desirable to extend our observations over the entire electromagnetic spectrum. These observations are especially important for the hot stars which are in rapid evolution. Both their maximum energy output and the spectral lines which are critical for studying the abundances of important elements in these stars are in the currently-inaccessible ultraviolet.

Interstellar Medium: In the study of the interstellar medium, the question of the energy balance has been reopened by recent rocket investigations, which show more ultraviolet energy being released by radiative processes than had been previously supposed. Additional information is needed regarding the nature of interstellar grains, their absorption and scattering of starlight in a wide range of wavelengths, particularly in the infrared, and their interaction with the interstellar magnetic fields. In studies of the interstellar gas, astronomers have been handicapped by the lack of observation in the ultraviolet portions of the spectra where the principal spectral lines of the interstellar gases lie. These data promise to supply vital information on the chemical composition, the distribution relative to galactic features, and the mass motions and excitation processes which play an important role in the evolution of our galaxy.

Star Clusters and Galaxies: Star clusters, galaxies, and clusters of galaxies constitute the large-scale building blocks of the universe. The role and mechanism of these associations remain questions basic to the solution of the origin and evolution of our universe. The individual properties of the star cluster and the galaxy such as mass distribution, mass-luminosity ratio, angular momentum, gas and dust concentration, and energy balance are typical of the parameters needing study. At present, we have little knowledge of the nature and density of the material in intergalactic space, as observations in the visible spectrum have proved inconclusive. It is desirable to carry the observations into ultraviolet portions of the spectrum, where higher absorption can be expected to greatly increase the sensitivity of these measurements. Current theories in cosmology depend strongly upon the correct interpretation of the red shift. It is desirable to determine if this red shift is a constant over the whole electromagnetic spectrum, and also if it is a linear function of distance. Since the red shift for very distant galaxies is sufficient to shift the normally-observed spectral features into the unobservable infrared, detailed studies of the ultraviolet region of nearby galaxies and the infrared of very distant galaxies are essential to the detection of possible evolutionary effects during the billion or more years it has taken the light from the further galaxies to reach the earth.

Program

Long-Range: The great distances of astronomical objects outside of the solar system mean that they are both small in angular dimensions and apparently faint. Hence, for wavelengths shorter than one meter, the objects require long periods of observation with large radiation collectors having good angular resolution and accurate pointing. Radio-astronomical observations in wavelengths beyond the ionospheric limit require extensive antenna arrays to achieve good resolution. Thus, until an observatory on the moon is possible, experiments in this wavelength region will be limited to the sun and to low-resolution reconnaissance surveys. In the short-wave radio regions, astronomical sources are weak. It is possible that the development of large inflatable balloons will provide the necessary collecting area for observations in this region. To provide the necessary pointing accuracy and observing time for experiments in the infrared, optical, ultraviolet and X-ray regions of the spectrum, development has begun on an orbiting stabilized platform. It will be possible to point this platform toward any point in the sky and to hold it in that direction for periods from a few minutes to an hour, with sufficient accuracy to allow continued observations of individual celestial objects. The satellite will contain instruments of moderate size which can be completely controlled from the ground, thus providing a remotely operated observatory which can perform most of the functions of a ground-based observatory. Although the sky above the earth's atmosphere will be dark, the presence of sunlight scattered within the vehicle itself may be disturbing. The eventual establishment of an astronomical observatory on the moon will eliminate this difficulty, since the moon itself can provide an effective shield against the sunlight. Moreover, the establishment of an observatory on the moon will undoubtedly make feasible larger equipment than can be placed on a satellite-borne platform. The execution of these programs will require the development of not only a stabilized platform and its pointing controls, but also specialized optical equipment and radiation receivers for particular wavelength regions, especially adapted for a particular program, and improvements in telemetering techniques so that transmission to ground stations of spectroscopic data of adequate scope and resolution will be possible. For planetary studies, the planetary satellites and planetary probes planned for the atmospheres program will also be useful for providing information on the surface conditions and interior structures of the planets.

Immediate: The immediate program includes the exploration of the moon; reconnaissance measurements in the ultraviolet region of the spectrum to determine the brightness and positions of interesting regions of the sky; preliminary testing of equipment and techniques to be used later on the stable platform; and studies of the sun in the ultraviolet and X-ray region with pointing controls somewhat less stringent than those to be used for the stable platform. The reconnaissance will continue and extend to the southern sky the survey of the newly-discovered extended emissions in the far ultraviolet in order to determine the nature and sources of these emissions. Stellar photometry measurements will be made in the near and far ultraviolet spectral regions to extend the magnitude systems to these wavelengths. Emphasis is being given to observations in the previously unexplored far ultraviolet and high-energy gamma-ray spectral regions. Studies of the solar ultraviolet and X-ray spectra will include their long-term variations, line profiles, distribution across the disk, and the spectra of the coronal X-ray emissions. In addition, long-wavelength radio receivers will be placed in satellites to study the brightness distribution of the sky in these wavelengths, the spectrum of the sun and its variation, and the absorption of the earth's ionosphere at various heights.

BIOSCIENCES

Objectives

To determine the effects on living terrestrial organisms of conditions in the earth's upper atmosphere, in space, and in other planetary atmospheres. To determine the effects of flight through space on living organisms. To investigate the existence of life throughout the solar system, and to study in detail whatever extraterrestrial life forms exist.

Problems

The opportunity now exists to conduct fundamental life-sciences research in satellites and space probes. In such research, conditions in space and conditions during flight through space enter as new experimental variables. Principal interest lies in the components of the space and space-flight environment that are irrevocably different from the terrestrial, such as radiation and the altered gravity state. The former is qualitatively and quantitatively different from terrestrial radiation and looms as a far more important problem than originally thought. The latter offers the possibility of elucidating biological processes known to be effected by weight or apposition of one part against another, such as cell division and organogenesis. These and other areas of study could be carried out in satellites or space probes from which specimens under study could be recovered.

More specifically, fundamental experiments on living organisms in the satellite environment or in other types of space vehicles and stations should be conducted to cover the following general topics: 1) Animal navigation and orientation, 2) Mitosis and embryology, 3) Plant morphogenesis, 4) Geotropic response of plants to altered gravitational fields, 5) Biological rhythms and cycles, 6) Altered gravitational effects on blood circulation in animals, 7) Vestibular physiology, 8) Neuropharmacology—effects of tranquilizers, motion sickness drugs, etc., 9) Effects of cosmic radiation, 10) Tolerance limits for combined stresses, 11) Physiological and psychological deterioration, 12) Effects of acceleration and deceleration.

There has been considerable speculation about the possibility of the existence of extraterrestrial life forms. The debate ranges from whether or not life exists on Mars and Venus, and if so in what form, to whether or not spores and similar life forms can survive the rigors of interplanetary space. Investigations of these topics must, for the most part, await observations which can be made on direct samples and studied in space laboratories of the future. It is conceivable, however, that with proper and specialized instrumentation and remote sampling techniques it may be possible to obtain evidence of primitive or complex organic material without the presence of a scientist and a laboratory in the sample area. Elaborate instrumentation and the recovery of records, or advanced telemetering techniques could provide information about the nature of biochemicals on the planets.

Program

The program in biosciences is still being formulated. Immediate steps include a series of discussions with leading bioscientists to firm up important initial lines of attack.

NASA and Industrial Property*

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Summary—**The purposes and powers of the National Aeronautics and Space Act are described briefly, particularly as they affect the electronics industry, as an introduction to a more extended discussion of the provisions of the Act relating to patent rights and rights to trade secrets and proprietary information generally. The stringent nature of the latter provisions is stressed, and adverse effects of strict construction and enforcement on the electronics industry analyzed. Mitigating regulations under which the Act will in fact be administered are discussed.**

INTRODUCTION

THIS PAPER concerns itself generally with the National Aeronautics and Space Action of 1958 (Public Law 85-568), hereinafter referred to as the Space Act. More particularly, we shall be concerned with the effect of the Space Act on industrial property, such as patent rights, confidential information, and trade secrets. We shall endeavor to derive the legal, business, and economic consequences of the Space Act as these might flow from the terms of the Act itself, and from the interpretations of the Act being accorded to it by its current administrators.

The Space Act establishes a civilian agency, called the National Aeronautics and Space Administration (NASA). The Act provides for an Administration, and for a National Aeronautics and Space Council which exercises high level or policy control of NASA. The latter is presided over by the President of the United States, and includes among its members the Secretary of State, the Secretary of Defense, the Administrator, the Chairman of the Atomic Energy Commission, and others. Its basic function is to set policy for NASA. In terms of corporate organization, NASA has, as Chairman of its Board, the President of the United States, and on its Board of Directors some of the highest officers of the United States Government, although *pro forma* the Council is not part of NASA. The Council is also a coordinating agency between NASA, DOD, and scientific agencies of the Government.

A basic function of NASA is to conduct "aeronautical and space activities" sponsored by the United States, except those activities which are "peculiar to or primarily associated with the development of weapon systems, military operations or the defense of the United States." The exclusion extends to research and development "necessary to make effective provision for the defense of the United States." These latter functions remain the responsibility of the Defense Department.

The term "aeronautical and space activities," which constitute functions of NASA, are very broadly defined in the Act, and NASA is not restricted by the terms of the Act to activities having a direct or necessary relation to outer space. NASA personnel insist that the broad language of the Act was intended merely to minimize restriction on activities of NASA, without any intention of involving NASA in activities not concerned with outer space. Despite these protestations, the Act itself provides that, apart from defense activities, NASA has cognizance of aeronautical as well as space activities and that its objectives, in these fields, are 1) to expand human knowledge of phenomena in the atmosphere and space, 2) to improve the usefulness, performance, speed, safety, and efficiency of aeronautical and space vehicles, 3) to develop and operate vehicles capable of carrying instruments, supplies, and living organisms through space, 4) to establish long-range studies of the benefits, opportunities, and problems involved in aeronautical and space activities, 5) to preserve the United States as a leader in aeronautical and space science and technology, 6) to convey information concerning its accomplishments to defense agencies where these accomplishments have military value or significance, 7) to receive from the military agencies all information which may have value or significance to NASA, 8) to cooperate with other nations in peaceful application of aeronautical and space activities, and 9) to promote the most effective utilization of scientific and engineering resources of the United States, with close cooperation among all interested agencies of the United States, in order to avoid unnecessary duplication of effort, facilities, and equipment.

The Act defines "aeronautical and space activities" as meaning 1) research into and solution of problems of flight within and outside the earth's atmosphere, 2) development, construction, testing, and operation for research purposes of aeronautical and space vehicles, and 3) any other activities which may be required for the exploration of space. The Act defines "aeronautical and space vehicles" as meaning aircraft, missiles, satellites, and other space vehicles, manned and unmanned, together with related equipment, devices, components, and parts.

It immediately becomes apparent that the purpose of the Act, as stated in the Act itself, is not restricted to space activities. NASA is empowered, and in fact directed, to concern itself with aircraft, and with related equipments, devices, components, and parts, and to improve the usefulness, performance, speed, safety, and efficiency of aeronautical vehicles. It follows that NASA may, within the terms of its authority, concern itself with such things as telemetering, communication systems, guidance systems, radar systems, navigational systems, and, in terms of devices and components, may concern itself with the entire electronics industry.

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* Original manuscript received by the IRE, December 2, 1959.

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A further function of NASA which has not received attention heretofore relates to point 9); *i.e.*, that NASA is to so conduct the aeronautical and space activities of the United States as to contribute to the most effective utilization of scientific and engineering resources of the United States in order to avoid unnecessary duplications of effort, facilities, and equipment. Since the purpose of the Act in relation to aeronautics, space activities, and any adjunct thereto, is extremely broad, it is not far afield to state that the Act provides authority to regiment the scientific and engineering resources of the United States. Avoidance of the duplication of effort in telemetering, for example, or in radar, or in radio communications or the avoidance of unnecessary duplication of effort, facilities, and equipments in these fields, imply powers having far reaching implications. This is not to say that the power will be utilized to the extent for which the Act provides authority, but merely that the authority exists and that the Council is of sufficiently high level that if NASA decided to exercise the authority granted to it, there would be no one to intervene unless Congress should decide to modify the Act or to repeal it.

The Act provides that it shall be the duty of the President, as a member of the National Aeronautics and Space Council, to survey all significant aeronautic and space activities of all agencies of the United States engaged in such activities. Obviously, this includes the Defense Department. The Act further orders the President, as follows: He shall develop a comprehensive program of aeronautical and space activities to be conducted by agencies of the United States, and designate and fix responsibility for the direction of these activities. He shall provide for effective cooperation between NASA and the Defense Department in respect to such activities, and specify which activities may be carried on by both agencies, notwithstanding assignment of primary responsibility to one of these. The latter provision obviously provides for concurrent jurisdiction of defense matters in NASA and the Defense Department should the President decide that this is necessary or advisable. Moreover, the President is empowered to resolve differences among the departments as to whether a particular project is or is not an aeronautical and space activity. Since aeronautical and space activity is so broadly defined as to include almost any conceivable activity in the field of science, enormous vistas are opened up.

PATENT PROVISIONS

We have reviewed the purposes, functions, and powers of NASA, as provided by the Space Act, as a prelude to discussion of the patent provisions of the Act. Were these powers and functions restricted to the field of space activities, *i.e.*, to satellites, space platforms, interplanetary travel, and the like, provisions of the Act relating to patents and to industrial property generally would not be of primary interest to the greater part of the electronics industry. However, since the Act is so broadly worded that there is no field of science in which its voice may not be heard in due course, and since there are few scientific functions of the Defense Department which NASA may not absorb or parallel eventually, the patent provisions and the industrial property provisions of the Act acquire great significance.

Section 305 of the Act provides that "whenever any invention is made in the performance of any work under any contract of the Administration and the Administrator makes certain determinations, the invention and patents predicated thereon shall be the exclusive property of the Government." This in itself appears to be similar to provisions found in the Atomic Energy Act, but involves a policy which is not followed by the Department of Defense. It becomes pertinent, then, to consider the meanings of the terms "invention," "made," "performance," "work," and "contract." The act is explicit in defining some of these. For example, the term contract is defined in Section 305(j)(2) of the Act, as follows: "The term contract means any actual or proposed contract, agreement, understanding, or other arrangement, and includes any assignment, substitution of parties or subcontract executed or entered thereunder."

One who enters into a contract may, as a general proposition of law, agree to forego rights to patents which may arise in its performance. It is his privilege to refuse to enter into the contract if he does not wish to forego his rights to patents. A departure from previously known practices arises in the words "proposed contract." The term can well be construed to mean that one who submits a proposal to NASA, thereby and without a contract or any understanding, or any consideration of any kind, transfers rights to patents to NASA. A further area worthy of thought relates to the term "subcontract," which is not defined. Is a supplier to a NASA contractor *per se* a subcontractor, and thereby one who performs work under a contract with NASA?

We may envisage, for the sake of example, a course of action in which a company interested in electronics makes a proposal to NASA, the proposal being sufficiently vague that NASA may refuse to consider that it includes a conception of an invention. The company is now a "contractor" by virtue of having made the proposal. It is then given some encouragement to proceed by NASA, at some expense to itself, to develop its proposal to completion in respect to means and methods. It soon has a complete conception of an invention, which it has completed while a contractor. NASA is pleased with the proposal but decides to award a contract to perform the work thereunder to a competitor, on the ground that the latter is better qualified for the purpose. Under the terms of the Act, NASA can take full right, title, and interest to the invention so made, and refuse to compensate the contractor for his efforts. It is true that under the terms of the Act the Administrator is not required to take full right, title, and interest, as we shall see, but he is required to take at least a royalty-free licence.

The term "made" when used in relation to any invention, means 1) conception, or 2) first actual reduction to practice. One who merely conceives of an invention and who does no more can thereby have forfeited all rights to the invention to NASA if he is an NASA contractor. One who conceives of an invention prior to making a proposal thereon to NASA has made an invention prior to such proposal, and at that point the invention is his own. On submitting the proposal he has entered into a contract, but since the invention was made prior to entering into the contract, the inventor may retain his rights. If the inventor actually reduces to practice following the proposal, without an NASA contract, and certainly if he receives a contract and thereafter reduces to practice, he forfeits his rights to the invention, because he has reduced to practice while a contractor.

The Act does not define the word invention, but in specifying what reports shall be provided under NASA contracts, provides for "a written report concerning any invention, discovery, improvement, or innovation." This would appear to go further than does the Defense Department. An innovation may be a very slight thing, whereas an invention goes beyond what can be expected of a man skilled in the art in which he is working. Furthermore, the report is required to contain "full and complete technical information," a requirement which should be considered in relation to the further requirement that NASA disseminate the information which it collects. The Defense Department has not heretofore generally required full and complete technical information concerning inventions, but has usually been satisfied with sufficient information to enable a patent application to be prepared. There is a great distinction between information which is sufficiently detailed to form a basis of a patent application, and full and complete technical information. The latter may well be interpreted to mean complete design information, or manufacturing information. If NASA makes a practice of acquiring full technical information and disseminating the same, a great mass of heretofore proprietary information may eventually become public.

Section 305 provides that inventions made in the performance of work under a contract with NASA shall be the property of the United States, and that if such invention is patentable, a patent shall be issued to the United States upon application made by the Administrator. These words, if taken at face value, might indicate that the Administrator is to apply for patents in his own name. This may be merely lax language in the statute, since heretofore under United States law the primary applicant for Letters Patent has been the inventor or inventors, unless he or they were dead or mentally incompetent. In the case of the death of an inventor, his executor or the administrator of his estate may file in his name, and in the case of an insane inventor, his guardian may file. There is, however, one additional situation in which a person other than an inventor may become an applicant for patent. Rule 47 of the Rules of Practice of the U. S. Patent Office provides that "whenever an inventor refuses to execute an application for patent, or cannot be found or reached after diligent effort, the person to whom the inventor has assigned or agreed in writing to assign the invention, or who otherwise shows sufficient proprietary interest in the matter, justifying such action, may make application for patent on behalf of and as agent for the inventor." We may, therefore, find, in cases where conflict arises as to whether or not an application is to be filed, or to whom it belongs, that the Administrator will, pursuant to Rule 47 of the Rules of Practice in the United States Patent Office and pursuant to the authority provided in the Act, file on behalf of the inventor, and as his agent.

Section 305 provides for certain fact determinations to be made by the Administrator, upon the basis of which he may apply for a patent, covering work done under an NASA "contract." The contractor may dispute such fact findings. In summary, if the Administrator finds that 1) the person who made the invention was employed or assigned to perform research, development, or exploration work and the invention is related to the work he was employed or assigned to perform, or that it was within the scope of his employment duties, then whether or not the invention was made during working hours or with a contribution of the Government, or the use of Government facilities, equipment, materials, allocated funds, information proprietary to the Government, or services of Government employees during working hours, the patent belongs to the Government; 2) where the person was not employed to invent or to perform research and development or exploration work, but the invention is nevertheless related to the contract, or to work or duties he was employed or assigned to perform and was made during working hours, or with a contribution from the Government of the sort referred to in situation 1) above, NASA is authorized to seize the patent rights involved, and, in the terms of the Act, the Administrator "may apply for a patent."

In essence, under situation 1), inventions of research and development personnel working under a NASA contract almost inevitably belong to the United States so long as the invention is related to the work of the contract, even if it is made on the inventor's own time, with his own money, and with no contribution from the Government. Situation 2) goes beyond situation 1) in that any invention made by personnel not hired to do research and development, and working under an NASA contract, belongs to the United States if the work is related to the contract, but then only if the work was done during working hours, or with a Government contribution of one of the types specified in situation 1).

Considerable confusion may arise in respect to NASA contractors who have personnel working in part on NASA contracts and in part on commercial or Defense Department contracts. This may readily occur in respect to supervisory personnel and consultants. We need only envisage, for example, a telemetry group with one NASA contract, one Defense Department Contract, and an allocation of company money, working on three subjects, all relating to telemetering. The group supervisor makes an invention during working hours, of primary application to the Defense Department contract. The invention is certainly related to the work on the NASA contract, since both relate to telemetering. Is the company subject to the Space Act, in respect to that invention, or can it retain commercial rights as normally provided in Defense Department contracts?

Under Section 305(c) of the Act, the Commissioner of Patents is required to refuse to issue patents which he believes have "significant utility" in the conduct of aeronautical and space activities, unless an applicant on request files a statement under Oath, setting forth the full facts concerning the circumstances under which such invention was made and the relationship of the invention to NASA contracts.

After the statement under Oath is filed, the Administrator is given 90 days to request that the patent be issued to the United States. If he does not do so, the patent issues to the applicant. If he does so, however, the applicant may contest his findings by filing a request for a hearing before a Board of Patent Interferences, which acts as an appellate tribunal in this respect. From the determination of the latter each party to the controversy may appeal to the Court of Customs and Appeals.

Even if the Administrator takes no action within the 90 days allowed, and the patent issues to the applicant, the matter may be reopened by the Administrator within five years, if he has "reason to believe the statement filed by the applicant contained any false representation of any material fact." Note that fraudulent representations are not required. Innocent but false representations are adequate.

The Administrator is authorized to waive his right to acquire full rights in inventions, for the United States, if he determines that "the interest of the United States will be served thereby." But his waiver can in no case go so far as to waive a royalty-free license in favor of the United States and foreign countries with which the United States has commitments in this respect.

The Administrator, under Section 305(g) of the Act, can issue licenses under United States patents acquired and can protect his title and rights. He can also require holders under which the Government holds a license to protect such inventions or discoveries. It is not clear whether the Administrator may sue for infringement, require patentees to sue for infringement, or grant licenses subject to royalty payments. In general, under Defense Department procedures, the Government has never asked for a royalty, nor sued anyone for infringement, nor required any holder of patents under which it had rights to sue for infringement.

PROPRIETARY INFORMATION

The impact of the Space Act on proprietary rights goes farther than its impact on patent rights. Section 303 of the Act provides that "information obtained or developed by the Administrator in the performance of his functions under the Act shall be made available for public inspection," except security matters and information authorized to be withheld by Federal statute. The word "shall" appears to be one of command.

Section 102(c) provides for interchange of information between Defense Agencies and NASA on a two-way basis. The Defense Agencies are thus required to supply NASA with information, which the latter is required, not authorized, to make available for public inspection.

Under Section 203(a)(3) NASA is required to provide for the "widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

The extent to which proprietary information, such as manufacturing drawings, design information, performance data, and the like, will be disseminated and made public, under the quoted directive, remains to be seen. However, the Act, by its terms, gives the Administrator little leeway. It states that the information "shall be made available for public inspection."

The writer predicts that the provisions of the Act relating to patents will, as actually administered, be found to be certainly no more burdensome than is the Atomic Energy Act, and probably to rather closely parallel the Defense Agency practice. The situation with respect to dissemination of information, on the other hand, may prove to be the sorest point of all, and one which is far more directly of interest to many contractors than are the patent provisions. It is within the personal experience of the writer's firm to have received requests from the Defense Department for full manufacturing information concerning a client's proprietary product, which had been bought off the shelf, on the basis that this was required in order to enable the agency concerned to comply with the Space Act. Because of this there seems to be a current opinion, existing at least in some elements of the Defense Department, that the Space Act requires changes in procedures in the Defense Department.

CONTRIBUTIONS AWARDS

Section 306 of the Act authorizes the Administrator to make monetary awards. He may do this on his own initiative, or upon application of a person or firm, and the amount of the award and the terms upon which the amount may be awarded are left to the discretion of the Administrator. The award must be for a scientific or technical contribution to NASA, which is determined by the Administrator to have significant value in the conduct of aeronautical and space activities. An Inventions and Contributions Board is established, before which hearings may be had by applicants for awards, and has the function of transmitting to the Administrator its recommendations as to the terms of awards to be made.

The factors which the Administrator shall take into account, in making an award, are defined by the Act as follows: 1) the value of the contribution to the United States, 2) the amount of money which the applicant has expended on his own account for the development of the contribution, 3) the amount which the United States has paid toward such expenditure, except that in the case of an officer or employee of the Government salary will not be considered to be such a contribution.

As a consideration for the receipt of such an award, the applicant is required to surrender all claims pertaining to the contribution which he may have against the United States Government or against foreign governments which have suitable agreeements with the United States.

Awards of less than $100,000 appear to be within the sole discretion of the Administrator, but awards exceeding $100,000 require the consequent concurrence of the Congress, which the Congress can convey by failing to object for 30 days after notice to it of intention to grant the award, these 30 days to subsist within a regular session of the Congress.

General Objections

The patent provisions and the proprietary rights of the National Aeronautics and Space Act have been objected to by the Electronic Industry Association. The basic grounds of objection is that the provisions of the Act "may well constitute a first step in the direction leading to the destruction of the American system of patents and trade secrets."

As the patent system is presently established, a long subsisting statute (28USC1498) provides that "whenever an invention described and covered by a patent of the United States is used or manufactured by or for the United States, without license of the owner thereof, or lawful right to use or manufacture the same, the owner's remedy shall be by action against the United States in the Court of Claims for the recovery of his reasonable and entire compensation for such use and manufacture."

The quoted statute in effect provides the United States with a license, not royalty free, under every United States patent. It also provides the patent holder with a procedure for obtaining a reasonable royalty for violation of such patent by the United States, or in its behalf by a contractor, and since the statute provides the sole remedy for the patent holder, no contractor need concern himself with the possibility of an injunction preventing him from fulfilling a Government contract, and the Government in no case can be impeded in procuring equipment, by virtue of any subsisting patent rights. The Government is primarily financially responsible for patent infringement. It can seek reimbursement from a contractor who has infringed without the concurrence of the Government, in certain cases.

The electronics industry recognizes that the Government must adopt procedures which shall assure the Government that it will not be required to pay excessive amounts for equipment which it purchases, and it is only fair that it should not pay a royalty on equipments which it has paid for developing, or toward which it has paid in considerable amount for development. It is for this reason that the electronics industry generally feels that it is reasonable that the Government receive a royalty-free license on inventions made in carrying out research or development work, where the latter is required by a contract with the Government. Industry feels that there can be no objection to the Government filing for and receiving patents based on research which Government has financed, as a protective measure, to prevent subsequent inventors from obtaining patents on the same inventions. However, industry feels that many of the inventions made by industry in the course of performance of research and development contracts, and under which the Government receives free licenses, in fact are made because of a wide area of experience acquired by the contractor without Government support. Where a contractor has acquired a great deal of knowledge and experience, and developed unusual capabilities in certain technical fields, it can be reasonably argued that further inventions made in this field are not fully paid for by the Government merely because the contractor is operating under a Government contract. It is therefore felt that to require contractors to convey to the Government full right, title, and interest to inventions made by them in the course of performance of a Government contract can be, in effect, confiscatory.

Specifically, the industry feels that giving exclusive title to the Government for every invention, made in the performance of any work under any relationship which may exist with NASA, whether or not the Government contributes to the work, or to the invention, and whether or not the invention relates to space activities, presents an excessive tax on industry and does not take account of the realities of the many situations which may arise.

Industry further feels that in providing that the Commissioner of Patents police all patent applications relating to aeronautics and space activities, and in granting him power to refuse to issue any patents thereon unless the applicant therefor clarifies his relationship with respect to NASA, and further requiring certain costly appellate procedures where there is a difference of opinion, involves placing a heavy burden not only on firms having some sort of contractural relation with NASA, but also on firms which do not have such relations. The electronics industry also feels that it is highly inequitable to subject a contractor who enters into a contract with NASA, or who submits a proposal to the Administrator, or who becomes a subcontractor of an NASA contractor, to the danger of having his trade secrets, engineering information, design and manufacturing information, and the like, published and disseminated, regardless of whether or not compensation is afforded therefor.

Industry does not feel that the contributions awards sections of the Act provide an adequate remedy, since in fact they do not provide any legal remedy, but merely provide the Administrator with authority to grant cash awards, within his own discretion.

Employment Agreements

The question of the conditions under which the Government obtains patent rights, pursuant to the Space Act, deserves some further analysis than has been given. These conditions are established by Section 305(a) of the Act, in two clauses, and the provisions specify that when an invention is made in the performance of any work under any contract of the Administration, and the Administrator makes certain fact determinations, the invention shall belong to the Government. This portion of the Act requires that the invention involved "be made in the performance of any work under any contract of the Administration." However, clause (1) goes on to state that the Administrator can obtain title to the invention whether or not the invention was made during working hours, whether or not the invention was made with a contribution by the Government or the use of Government facilities, equipment, materials, allocated funds, information proprietary to the Government, or services of Government employees during working hours. It is a bit difficult to see how an invention can be made under an NASA contract, without allocation of Government funds, at least, so that these provisions of the Act appear to be contradictory; *i.e.*, the invention must have been made under a contract with NASA, yet the Government need not have contributed in any way to the invention, *i.e.*, need not have paid for the work nor provided facilities or equipment, or provided information. Also, whereas this section states in its initiating phrase that the invention must be made in the performance of work under a contract of the Administration, the following phrases do not make reference to contributions by NASA, but rather to contributions by the Government, which represents a much broader source for contributions. What is probably intended by this disturbing language is that if a contractor enters into a prime contract with NASA, or submits a proposal to NASA, or if a subcontractor submits a proposal to a contractor of NASA, or enters into a sub-contract with a contractor of NASA, and if he thereafter makes (conceives or first reduces to practice) an invention solely with his own funds, facilities, information, and the like, and without any contribution from the Government, that the invention nevertheless belongs to NASA, if NASA can trace some relationship of work done under the NASA contract, to the invention in question. The precise scope of this relationship is not defined, and presumably a relationship of subject matter is intended.

The preceding clause (1) involves a person who made an invention and was employed or assigned to perform research, development, or exploration work, and in such case the invention is required to be "related" to the work he was employed or assigned to perform. Clause (2), however, relates to persons who are not hired to invent or to do research. The inventions of such persons nevertheless belong to NASA if the invention is "related to the contract, or to the work or duties the party was employed to perform, and was made during working hours, or with a contribution from the Government of the sort referred to in clause 1." Such inventions might very well not belong to the employing company under employment contracts in effect, since many companies have employment contracts which exclude from their scope inventions not falling within the scope of the company's business, or providing for retention of certain employee rights under certain conditions, and since many companies do not have invention agreements with employees who are not hired to do research and development, or who are not primarily engineers. Additionally, outside consultants are often treated differently than are full time employees, in these respects.

It therefore appears to be incumbent on contractors who expect to do work for NASA to tighten their employment agreement policies to conform to the provisions of the Act, in respect to employees and consultants. In the first place, employees must have inventions agreements, whether or not the employees are engineers or are assigned to do research and development work, if they might conceivably make an invention. Secondly, the inventions agreement should have no exceptions therein to the classes or types of inventions which the employer can capture, however reasonable these might appear to employer and employee. Any exception can lay the groundwork for a claim by NASA to an invention which the employer has acquired no legal right to convey.

The material presented herein develops those aspects and possible interpretations of the Act which are the most unfavorable from the point of view of industry. We have indicated briefly that the Act may be administered more favorably than is suggested by these adverse interpretations, but we also stress that it is not good Government to pass legislation which is subject to unfavorable interpretation, so that future Administrators thereof, or courts, could at will implement the legislation in a manner which is distinctly unfavorable to those affected by it. At the same time, it is unfair to describe the unfavorable possibilities inherent in the language of the Act without discussing the relaxing regulations under which the Act is currently being implemented. These have been promulgated recently and are found in Vol. 24, No. 212, of the Federal Register, pp. 8788 to 8790.

It will be recalled that the Act gives the Administrator power to waive certain patent rights; *i.e.*, he can take a royalty-free license, and need not take the entire right, title, and interest in any patent, if he believes the interests of the United States will be served thereby.

Thus, the Administrator has established as policy that he may waive his right and assume that such waiver is in the interest of the United States, where "(a) the stimulus of private ownership of patent rights will encourage the development of the invention to the point of practical application earlier than would otherwise be the case, or (b) there are substantial equities justifying the retention of private rights in the invention."

Waiver will not be granted where an invention is primarily adapted for and especially useful in the development and operation of space vehicles and missiles, or where an invention is of basic importance in research in this field, except that in the latter case the Administrator may grant a waiver on such terms as seem to him appropriate.

A *prima facie* case is made out for waiver, 1) where the invention was conceived prior to and independently of entering into an NASA contract, but was first actually reduced to practice in the performance of work under a NASA contract, and the invention is covered by a United States patent issued or application filed prior to the award of the contract, 2) where nonprofit organizations are involved and certain fact situations exist, 3) where the invention has incidental utility for NASA, but substantial promise of commercial utility, 4) where the invention is directed specifically to a line of business of the contractor with respect to which the contractor's previous expenditure of funds has been large in comparison with the amount of funds supplied by NASA.

This portion of the regulation points up the urgency of filing patent applications on inventions before proposals incorporating the inventions therein are submitted to NASA, since such a procedure clearly brings one within the waiver provisions, if the invention is in the proper category.

The regulations proceed to discuss conditions under which a waiver, once granted, can be voided by the Administrator. Waiver granted for a new conception for which a patent application has been filed, or waiver granted because the invention relates to a line of business of the contractor in which it has expended considerable funds, are not subject to voidability. To provide an example, a contractor in the field of telemetry, who conceives a new invention in this field, who applies for a patent thereon, and who thereafter proposes the invention to NASA as a subject for a research and development contract, would be very likely to retain patent rights subject to a free license on behalf of the Government, and such patent rights would not be subject to future voidance.

A waiver granted in respect to an invention which does not enjoy freedom from voidability must be confirmed by certain acts or practices of the patent owner, which must take place on or before the end of the fifth year from the grant of the patent, or the end of the eighth year from the date of acceptance of the waiver, whichever is sooner. The Act, in such case, requires 1) development of the invention to the point of practical application, or 2) making the invention available for licensing either royalty free or at a reasonable royalty basis, or 3) some equitable excuse for failing to fulfil the stated conditions.

Little would be gained by a full discussion of all the details of the regulation in respect to waivers, in an article of this character, but enough has been said to indicate that the actual practice of NASA under the present Act may rather closely parallel, in final and net effect, the Defense Department practice under its present procurement regulations (ASPR).

It further seems reasonable to assume that the entire Administration of the Act, insofar as it relates to proprietary or industrial property will be administered in a manner which appears reasonable and equitable to the Administrator, and, in respect to patents, that the Defense Department practice will be paralleled insofar as the Act permits discretion, and even in respect to those portions of the Act which are not presently dealt with by the regulations. One of the practical reasons for such a conclusion is that NASA cannot hope to obtain the services of sufficient patent attorneys to enable it to capture any large volume of inventions. It must concentrate on the most important inventions. Furthermore, NASA must deal with contractors over long time periods, and in any dealings between any parties, attempts to depart from equitable principles by one of the parties is not good business practice.

The portions of the Act which have not been ameliorated by the regulations, and in respect to which the Administrator appears to have relatively small scope for amelioration, relate to the publication provisions of the Act, and to the capture of technical information from contractors and their subsequent publication. Insofar as the Act is inconsistent with the Copyright statutes, it may well be that the Act supersedes these. It is the belief of the writer, however, that, in due course, regulations will be established in respect to publication, which will be reasonably unobjectionable and will conform more or less with Department of Defense practices, with which industry has learned to live.

It might also be well to stress that the waivers provided for by the regulations are not granted as a matter of right, but rather that the fact situation provides a *prima facie* basis for a waiver. The Administrator is entitled, in each case, to take all the facts into consideration and to make a finding in each case, and, in fact, is required to so do by the Act. It therefore follows that a case may have to be made out by contractors for a waiver in respect to each invention for which a waiver is sought, and therefore that contractors must be very careful to make and keep records consonant with allegations that a waiver in a given case is in the interest of the United States, and that no peculiar equities in favor of the United States and against a waiver have arisen in connection with the conception or the reduction to practice of the invention, or by virtue of the contractor's own commercial practices.

A Comparison of Ion and Plasma Propulsion*

S. W. KASH†

Summary—**Several important features and parameters of ion and plasma accelerators for propulsion are compared. Estimates for the thrust of individual ion and plasma acceleration units are given. Impulse measurements for a collinear electrode plasma accelerator are presented. The maximum thrust for an ion gun does not depend on the diameter of the beam, but primarily on the accelerating voltage. Because of the relatively small thrust of the ion accelerator, a greater number of them will be required for a given total amount of thrust. Estimates indicate that the ion accelerator may be somewhat more efficient; however, further experiments are needed to determine the efficiency of both types of accelerators. Beam neutralization is a problem peculiar to the ion accelerator. Considerable research and development may be necessary to provide a satisfactory method for neutralizing the ions. An estimate of the power for neutralization is made. The variation of efficiency with specific impulse is discussed. Further experiments are needed to determine the most efficient ranges of specific impulse for both types of accelerators. Erosion is a serious problem in electrical propulsion; however, for a plasma accelerator it may actually be utilized to provide the propellant material.**

INTRODUCTION

IT has been amply demonstrated, that if adequate low-weight power plants were available, it would be advantageous for many space missions to use propellant velocities obtainable only by electromagnetic acceleration. A number of methods for accelerating ionized material have been proposed. Two of these, for which electromagnetic forces provide most of the acceleration, are ion drive and plasma drive.

Basically in all ion-propulsion schemes, ions or charged particles are produced and then electrostatically accelerated. The accelerating electric fields are provided by an arrangement of suitably biased electrodes. Provision must be made for the elimination of electrons of an amount equal to the positive charge and with velocities comparable to that of the positive charge. In plasma-propulsion devices, a neutral plasma discharge is produced and accelerated by rapidly varying intense magnetic fields. The accelerating magnetic fields are often provided by the discharge of large currents through the plasma and associated circuit elements. The large currents are supplied from special low-inductance high-capacitance electrical storage units.

How do ion drive and plasma drive compare? Which is likely to provide the superior propulsion system? These questions must ultimately be answered experimentally. It is quite possible that particular applications will be found for which each system is peculiarly suited. It is worthwhile to explore some of the salient features of ion-drive and plasma-drive accelerators, and to compare several important parameters, including specific thrust, efficiency, specific impulse, neutralization and erosion.

SPECIFIC THRUST

A quantity of importance for electromagnetic propulsion systems is the thrust developed per unit area. This will be referred to as the specific thrust, T_{sp}; it affects the efficiency and mass flow rate and is dependent on the specific impulse. It is apparent that too low a specific thrust will require a large accelerator area and will adversely affect the efficiency and weight of the accelerator.

The specific thrust can be expressed conveniently in terms of Maxwell stresses, that is, in terms of the electric and magnetic fields set up in the accelerators. We can estimate the electric and magnetic fields, respectively, for ion- and plasma-drive devices and compute from these results the maximum T_{sp}.

Ion-Drive Specific Thrust

In an ion-drive device (see Fig. 1), positive ions are produced at an anode and accelerated by an electric field toward a negatively-biased grid or cathode. Figuratively, we may imagine electric field lines emanating from the accelerating cathode and terminating on the ions. The tension along the field lines accelerates the ions backward; simultaneously, the cathode and attached rocket are accelerated forward. The forward thrust on the rocket is obtained from the forces between the cathode and the ions through the electric field tension. Per unit area of accelerator, this tension is $4.42 \times 10^{-7} E_c^2$ dynes/cm², where the field at the cathode E_c is expressed in volts/cm. Only field lines ending on ions contribute to the thrust. If the ion current is less than the maximum value, some of the field lines from the cathode will end on the anode and the thrust will be reduced. If E_a represents the field at the anode, T_{sp} will be proportional to $E_c^2 - E_a^2$.

For simplicity, let us assume the usual idealized one-dimensional case, with a separation, d, between the anode and cathode and a voltage drop, V_c, from the anode to cathode. In the absence of any ion current, the field between the anode and cathode will be uniform (equal to V_c/d) and the potential will vary linearly. In this case, $E_a = E_c$ and $T_{sp} = 0$. As the ion current density, j, is increased, some of the field lines will no longer terminate on the anode, but on the intervening ions instead. The potential will vary more slowly near the anode, and hence more rapidly near the cathode; the field at the cathode will be increased and the field at the

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* Original manuscript received by the IRE, November 2, 1959.

† Missiles and Space Division, Lockheed Aircraft Corp., Palo Alto, Calif.

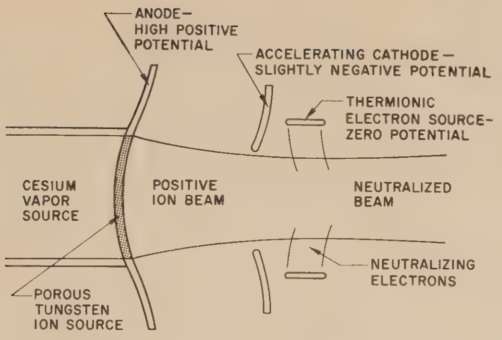
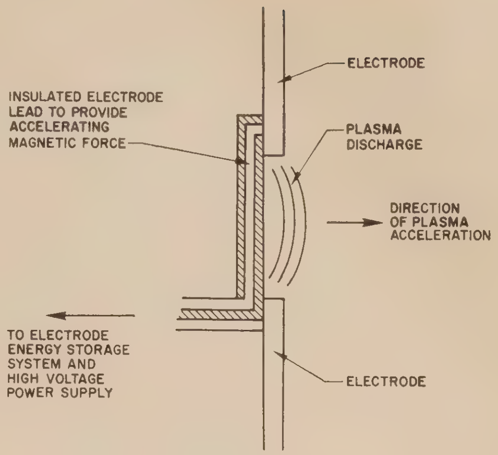

ANODE—
HIGH POSITIVE
POTENTIAL
ACCELERATING CATHODE—
SLIGHTLY NEGATIVE POTENTIAL
THERMIONIC
ELECTRON SOURCE-
ZERO POTENTIAL
CESIUM
VAPOR
SOURCE
POSITIVE
ION BEAM
NEUTRALIZED
BEAM
NEUTRALIZING
ELECTRONS
POROUS
TUNGSTEN
ION SOURCE

Fig. 1—Ion accelerator.

anode decreased. As j increases further, a value will be reached for which all field lines emanating from the cathode terminate on ions and no lines terminate on the anode. The field at the anode will then be zero and no more ions can be accelerated. The current density is said to be space-charge limited and the electric field at the cathode is now at a maximum.

The space-charge-limited case ($j=j_s$) is readily analyzed. First, equate the electric tension $4.42\times10^{-7}\ E^2$ with the momentum flux nmv, where m and v are the mass and velocity, respectively, of the ions, and n is the number of ions per second crossing a square centimeter. (The current density is simply n times the charge e per ion, or eT_{sp}/mv_c.) Now, express E and v in terms of the potential drop V and the distance x and integrate. The resulting familiar expression shows that the potential varies as the distance to the 4/3 power. Accordingly, the field at the cathode, which is now at a maximum, is 4/3 the zero current value and the maximum T_{sp} is $7.86\times10^{-7}\ (V_c/d)^2$ dynes/cm^2 or $16.4\times10^{-10}\ (V_c/d)^2$ pounds/foot^2.

It should be emphasized that this result is entirely independent of the mass or charge of the particles. As an example, for an applied voltage of 10,000 volts and an interelectrode spacing of one centimeter the specific thrust is at most only 0.16 pound/foot^2. For singly ionized cesium ions, this would provide a velocity of 1.2×10^7 cm/second and a maximum current density of 4.7 ma/cm^2.


ELECTRODE
INSULATED ELECTRODE
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ACCELERATING
MAGNETIC FORCE
PLASMA
DISCHARGE
DIRECTION
OF PLASMA
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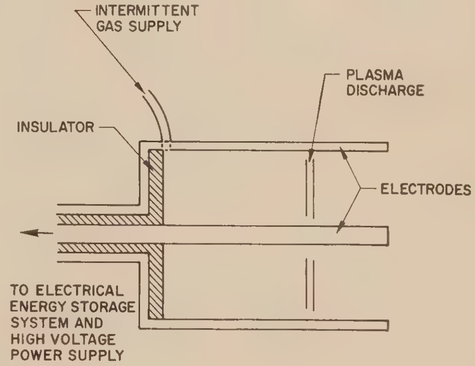
TO ELECTRODE
ENERGY STORAGE
SYSTEM AND
HIGH VOLTAGE
POWER SUPPLY
ELECTRODE

Fig. 2—Collinear electrode plasma accelerator.


INTERMITTENT
GAS SUPPLY
PLASMA
DISCHARGE
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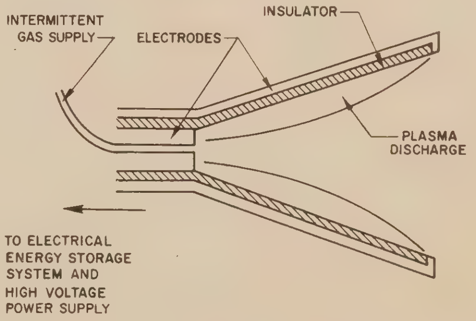
ELECTRODES
TO ELECTRICAL
ENERGY STORAGE
SYSTEM AND
HIGH VOLTAGE
POWER SUPPLY

Fig. 3—Coaxial electrode plasma accelerator.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POWER SUPPLY

Fig. 4—Plasma pinch accelerator.

Plasma-Drive Specific Thrust

In comparison with ion propulsion, a greater complexity of devices is available for plasma propulsion. Figs. 2–4 show three different electrode configurations capable of accelerating plasma. In each of these, a plasma introduced into the discharge region or produced by the discharge, is accelerated by the interaction of the current in the plasma and the current in the fixed part of the discharge circuit. Generally, the current elements in the parts of the circuit nearest the plasma contribute the most to the acceleration.

In the collinear electrode plasma accelerator (see Fig. 2), the principal force arises from the repulsion between the current element in the plasma and the antiparallel current element in the adjacent portion of the circuit. In the coaxial electrode system (see Fig. 3), the acceleration is provided by the repulsive interaction between the disk-sheet plasma current and the current in the central electrode. For the pinch accelerator, shown in Fig. 4, the accelerating force arises from the attractive self-interaction of the axially symmetric current sheet. Here the radial component of the current in the plasma contributes directly to the thrust; the axial component contributes indirectly through plasma compression and heating, much as in chemical propulsion.

For each system described, pulsed action is presumed and no steady magnetic fields are applied. In operation, large currents are obtained from the discharge of low-inductance high-energy capacitors. With careful design, the rate of rise of the magnetic field and the plasma conductivity can be sufficiently large so that there is little penetration of the magnetic field into the plasma during the acceleration. In this case the magnetic field in effect acts as a piston, and, for a field of H gauss, the magnetic pressure or T_{sp} is 0.04 H^2 dynes/cm². For example, for a field of 10,000 gauss, the specific thrust would be approximately 4×10^6 dynes/cm², or 8.3×10^3 pounds/foot².

Limitation on Ion Specific Thrust

As shown above, the specific thrust of an ion accelerator depends only upon the electric field intensity at the accelerating electrode, and is largely determined by the voltage and spacing between the cathode and the anode. The voltage itself is determined by the specific impulse and the mass of the ion. For example, with singly ionized cesium ions and an I_{sp} of 10^4 seconds, a voltage of about 7000 volts is required. Thus, to maximize T_{sp} it is necessary to minimize the interelectrode spacing.

Ion optics sets a limit on how small the interelectrode spacing d can be. Let D be the beam or cathode aperture diameter; we presume that to reduce erosion the aperture does not contain grid wires. As is the case for electron guns,[1] when d/D is less than unity, the field pattern within the ion beam should be different from that in the absence of the cathode aperture, and the average current density should be less than the space-charge-limited value based upon parallel-plane electrode theory. Furthermore, when d is less than D, there will be increased divergence of the beam. Thus, if a low-divergence high-intensity beam is to be obtained from the whole anode area, the interelectrode spacing should be larger than the beam diameter. With an accelerating potential of 10^4 volts, corresponding to an I_{sp} of 12,000 seconds for singly ionized cesium, and with a beam diameter and interelectrode spacing of, say, one centimeter, a maximum specific thrust less than 100 dynes/cm² is to be expected.

Argon-ion beam experiments[2] support the ion-optics considerations presented above. In these experiments, the equivalent perveance was measured for a number of circular-aperture arrangements at three different interelectrode spacings d. Table I lists microperveance values μ for the arrangement near maximum at all three spacings. The diameter of the cathode aperture is 1.0 inch, and the d values are based upon the beam profiles given by Harrison.[3] The last column presents the product $\mu(d/D)^2$ and shows the departure from parallel-plane electrode theory at the smallest d/D value. For $d/D = 1.5$, μ is close to the value predicted for parallel-plane electrodes. Although at $d/D = 0.5$ the current density is considerably less than the parallel-plane space-charge-limited value, the perveance (total current/voltage$^{3/2}$) itself is actually larger and is probably near maximum. It appears preferable, nevertheless, to use a larger spacing such as $d = D$, in order to reduce erosion.

TABLE I

VARIATION OF MICROPERVEANCE WITH d/D RATIO

Case	d/D	μ	$\mu(d/D)^2$
c	0.5	5.9	1.5
h	1.0	2.3	2.3
k	1.5	1.1	2.5

Consideration may be given to the use of smaller diameter beams with correspondingly smaller interelectrode spacings. For example, for a 3-mm diameter beam with a 3-mm interelectrode spacing and an accelerating voltage of 10 kv, the maximum specific thrust would be 873 dynes/cm², corresponding to a maximum current density of 52 ma/cm². It is interesting to note that for a given accelerating voltage and a fixed d/D ratio, the total thrust remains constant and independent of beam diameter. This results from the fact that the increase in T_{sp} is exactly compensated for by the decrease in beam cross section. Thus, the total number of ion guns for a given vehicle thrust will not vary greatly with ion-beam diameter. For an accelerating potential of 10 kv and with $d = D$, the maximum thrust per ion gun is 62 dynes, and about 7200 of them would be required to produce one pound of thrust.

To reduce radiation losses, smaller diameter beams are preferable. There are several factors, however, which provide a lower limit on the beam diameter or interelectrode spacing. For one, smaller diameters require larger current densities to be drawn from the ion source, which in turn requires a somewhat higher anode temperature,[4] and may also increase the erosion of critical electrode surfaces. Again, for a given voltage there is a minimum electrode separation set by the electrical-breakdown voltage gradient.

Limitation on Plasma Specific Thrust

For a plasma accelerator, the specific thrust depends upon the magnetic field intensity. In turn, the magnetic field is determined by the discharge current and geometry. If I is the current (in amperes) and d is a characteristic electrode dimension (in centimeters), H is of the order of $I/5d$ and T_{sp} is of the order of 10^{-3} $(I/d)^2$ dynes/cm². Now d can be of the order of a centimeter or less and I of the order of 10^5 amperes; hence, T_{sp} can be of the order of 10^7 dynes/cm².

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[1] J. R. Pierce, "Electron guns," in "Theory and Design of Electron Beams," D. Van Nostrand Co., Inc., New York, N. Y., ch. 10; 1949.

[2] E. R. Harrison, "Investigation of the perveance and beam profiles of an aperture disc emission system," *J. Appl. Phys.*, vol. 29, pp. 909–913; June, 1958.

[3] *Ibid.*, p. 911, Fig. 5.

[4] J. B. Taylor and I. Langmuir, "Vapor pressure of cesium by the positive ion method," *Phys. Rev.*, vol. 51, pp. 752–760; 1937.

In practice, such a high specific thrust cannot be achieved. Whereas the electric fields in an ion device act continuously, the magnetic fields in the plasma devices described act only intermittently. If we assume that the field is effective only 0.1 per cent of the time, the plasma-drive specific thrust is of the order of 10^4 dynes/cm^2. This is well over one order of magnitude greater than the maximum T_{sp} of an ion-drive device.

For a given peak current, the specific thrust will decrease with increasing aperture of the plasma accelerator, somewhat as it does with the ion accelerator. However, the plasma accelerator is not space-charge-limited, and a greater amount of power can be utilized in a single unit to accelerate a greater amount of propellant. It is possible to build a plasma accelerator with an effective area of between 10 and 100 square centimeters and still maintain a high specific thrust. Thus, a single plasma accelerator may be capable of providing a thrust of 0.1 pound or more.

Measurements on the Specific Thrust of a Plasma Accelerator

Experiments have been performed with a collinear electrode plasma accelerator, and measurements of impulse and efficiency have been made.[5] The specific thrusts obtained are in accord with the values estimated. In essence, the device (see Fig. 2) consists of a pair of collinear discharge electrodes connected to a low-inductance high-energy capacitor. The leads between the capacitor and the electrodes are arranged to keep the inductance of the discharge circuit as low as possible and also to provide the accelerating force for the plasma.

In operation, the region around the electrodes was evacuated and the capacitor was charged to a high voltage. A discharge was initiated by the introduction of plasma between the electrodes. For one set of measurements, the plasma for the discharge was produced by exploding a fine wire mounted between the electrodes and at right angles to the plane of the discharge circuit. In a second set of measurements, the discharge was initiated by the introduction of a minute amount of gas between the electrodes, with the major portion of the plasma being supplied by the electrodes themselves.

With the exploding-wire system a number of firings were made using different materials and different diameter wires. The vaporization of the fine wire was accomplished by discharging a small capacitor through it. Impulse measurements obtained are shown in the second column of Table II. The mass of the wire vaporized is shown in the third column, and the effective specific impulse determined from the impulse and wire mass is shown in the fourth column. The final column presents the efficiency obtained by comparing the computed kinetic energy of the ejected plasma with the initial energy stored in the main capacitor. As can be seen, the smaller-size wires yield the greater specific impulses and greater efficiency. Higher velocities and efficiencies than those presented should be possible by further improvement of the system.

For the expendable electrode system a small piston was used to admit a minute amount of triggering argon gas through a hole in the upper electrode. The impulses obtained were not sensitive to the amount of gas admitted, and as little as six micrograms of argon was adequate to trigger the discharge. The major portion of the propellant was obtained by erosion of the electrodes.

TABLE II

RESULTS OF IMPULSE MEASUREMENTS FOR THE EXPLODING-WIRE SYSTEM

Wire size	Measured impulse (dyne·seconds)	Mass of wire (mg)	Effective specific impulse (seconds)	Efficiency (per cent)
1 mil platinum	1380	0.90	1530	21
5 mil nichrome	1620	6.4	260	4
1 mil tungsten	1800	0.83	2210	39
2 mil tungsten	1750	3.3	540	9
5 mil nichrome	1750	6.4	279	5

TABLE III

VARIATION OF IMPULSE WITH VOLTAGE FOR THE EXPENDABLE ELECTRODE SYSTEM

Capacitor voltage V (kv)	Measured impulse I (dyne·seconds)	I/V^2 (arbitrary units)	CV^2/I (cm/second)
15	160	0.711	15.5×10^6
20	320	0.800	13.8
25	416	0.655	16.8
32	832	0.812	13.5
35	960	0.783	14.0

The impulse measurements for this system are shown in Table III. Analysis shows that both the impulse and the mass eroded from the electrodes should be proportional to the square of the initial voltage. The proportionality between the impulse and the square of the voltage is experimentally demonstrated by the results shown in the third column of Table III. A further consequence of the analysis is that both the specific impulse and the efficiency should be independent of the initial voltage. The specific impulse can be changed by varying the composition and/or the spacing of the electrodes.

Column four presents the effective velocity if the efficiency were one hundred per cent. With an assumed efficiency of 40 per cent the effective velocity computed from these data is about 6×10^6 cm/second. For this velocity the propellant mass ejected for a 35-kv firing is computed to be about 160 micrograms. With less than six micrograms of gas needed to trigger the discharge, over 96 per cent of the propellant is thus provided by the electrodes.

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[5] S. W. Kash and W. L. Starr, "Experimental Results with a Collinear Electrode Accelerator and a Comparison with Ion Accelerators," presented at American Rocket Society Meeting, Washington, D. C., November, 1959, paper no. 1008–59.

The data obtained with the collinear electrode system agree with the specific-thrust estimates made earlier for plasma accelerators. The end-on area of this device is of the order of 10 cm^2 and the firing time is of the order of 10^{-5} seconds. With about 10^3 dyne·seconds for the total impulse, the specific thrust is 10^7 dynes/cm^2. For a firing rate of one per second, the collinear electrode device produces between one and two grams of thrust. Only several hundred firings per second are necessary to produce a pound of thrust. This might be accomplished by a single device operating at this rate or by several similar devices operating at lower repetition rates.

Suggested Ways for Improving the Specific Thrust for Ion Drive

Two ways have been proposed for increasing T_{sp} for an ion accelerator. In the first, heavy-charged particles are suggested in lieu of ions. This would require the use of higher voltages to obtain the necessary specific impulse and would presumably yield more mass for a given current density and hence more thrust. The second way suggested is to use a double-grid accelerate-decelerate system to overcome the space-charge limitation on the current density.

In both of these schemes, higher voltages would be used to obtain the larger gradients necessary for an increase in T_{sp}. Unfortunately, if both the voltage and the voltage gradient are increased, electrical breakdown will ensue. Experiments have shown[6] that for vacuum insulation the maximum voltage and maximum voltage-gradient are interrelated. The results of these high-voltage breakdown experiments are shown in Fig. 5. Large gradients of the order of several million volts per centimeter can be sustained for voltages below 20 or 30 kv. Conversely, large voltages of the order of 1 million volts can be sustained only for small gradients, about 10^5 v/cm or less. Over a fairly wide range of voltage breakdown, the product of the voltage and voltage gradient is sensibly constant.

The breakdown data apply to cold, well-polished and outgassed metal surfaces, and result from a cascading of cathode electron emission and subsequent bombardment at the anode, and from ion and photon emission and subsequent bombardment of the cathode. Much smaller gradients and voltages can be sustained, with heated irregular surfaces, such as a porous tungsten anode and a partially-eroded cathode, and, of course, the deliberate presence of ions. Voltage gradients averaged over the plane of the cathode will be well below 10^5 volts/cm for applied voltages of the order of 10 kv.

If a higher voltage can be had only at the expense of a lowered voltage gradient, it is clear that little if any increase in T_{sp} can be obtained with a double-grid accelerate-decelerate system. In the heavy charged-particle accelerator, T_{sp} will actually be decreased; for even if efficient means were available to provide the micron or submicron particles with the maximum charge possible, accelerating voltages of the order of a million volts or more would be required to obtain a satisfactory specific impulse. This would entail a serious reduction in the voltage gradient and thus an even greater reduction in T_{sp}.

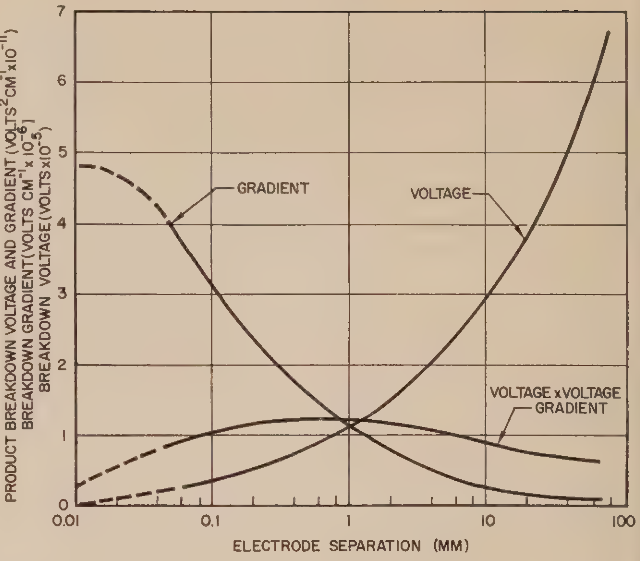

Fig. 5—Vacuum breakdown voltage between a one-inch stainless-steel ball and a two-inch stainless-steel disk. (After Trump.[6]) The lower curve has been added to illustrate the approximate constancy of the product of the breakdown voltage and the gradient.

NEUTRALIZATION

For the continued operation of an electrical propulsion system it is necessary to maintain charge neutrality on the vehicle. This requires the ejection of as many electrons as positive ions. Furthermore, the electrons must leave the space vehicle with about the same speed as that of the ions. For a plasma-drive device these conditions are automatically satisfied. On the other hand, for an ion-drive device special provision must be made to supply the neutralizing electrons.

It is not obvious that large-area ion beams can be efficiently neutralized. Neither an analytical nor an experimental demonstration to this effect has yet been presented. The major difficulty arises from the large disparity between the ion and electron masses. Experiments have shown that the current in a pencil-thick ion beam can be neutralized by a peripheral thermionic electron source.[7] However, these experiments have not, as yet, shown that charge neutrality was established downstream in the ion beam. This requires measurements to show that the ions and electrons have achieved the same axial velocity. It is possible, and indeed quite likely, that the neutralizing electron currents obtained in the experiment constitute a sparser but faster electron beam.

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[6] J. G. Trump, "Insulation strength of high-pressure gases and of vacuum," in "Dielectric Materials and Applications," John Wiley and Sons, Inc., New York, N. Y., pp. 147–156; 1954.

[7] R. C. Speiser and C. R. Dulgeroff, "Cesium Ion Motor Research," presented at Air Force Office of Specific Research Second Symposium on Advanced Propulsion Concepts, October, 1959; to be published.

It has been pointed out that if an ion beam is surrounded by an annular thermionic electron source, electrons can be drawn into the beam with large radial velocities and with average energies of about 2000 volts.[8] This, of course, represents a serious loss of energy and would occur at the expense of ion-beam energy. However, it has also been recognized that the presence of other electrons would reduce the electrical potential within the ion beam and reduce the energy loss. One estimate reduces the acquired electron energy to about half,[9] which still represents a considerable energy loss. Since the potential on the axis of a long cylinder of charge depends on the charge per unit length, the potential on the axis will also be fairly independent of beam diameter.

A complete analysis of the neutralization problem has apparently not yet been made. It is quite possible that if the ion beam were surrounded by an extremely copious supply of electrons, the neutralization within the beam would be sufficiently complete and the electrons would acquire only a few volts of energy upon being drawn into the beam. There is a practical difficulty involved here in that the electron source is also space-charge limited and a large potential gradient and/or large electron source area is needed to get a sufficient electron current. Fortunately, the electron mass is small, so that more modest gradients than needed for an equivalent ion-current density will suffice. If the electron-emitting area is comparable to the ion-source area, and if its distance to the center of the ion beam is comparable to the ion-interelectrode distance, then a potential of only a few hundred volts will be needed to obtain the necessary electron current.

We may expect, then, some balance to be achieved by which the potential at the center of the ion beam relative to the electron-emitting surface is slightly above that necessary to provide the neutralizing electrons. There will still be a substantial energy loss in the form of electron kinetic energy. It should be possible, in principle at least, to reduce this further by the use of special electron accelerating surfaces at the electron source. Modest voltages below 100 volts would probably be sufficient. Thus, the loss to radial electron kinetic energy might be reduced, although at the expense of greater complexity of design and operation.

EFFICIENCY

The kinetic power and mass-flow rate per unit area are readily expressed in terms of the specific impulse and specific thrust. With I_{sp} in seconds and T_{sp} in dynes/cm², these are, respectively,

$$P_{sp} = 5 \times 10^{-8} g I_{sp} T_{sp} \text{ watts/cm}^2$$

$$M_{sp} = T_{sp}/g I_{sp} \text{ gm/cm}^2 \text{ seconds.}$$

For a cesium-ion accelerator with an accelerating voltage of 10 kv and an anode to grid spacing of only one centimeter, $I_{sp} = 1.2 \times 10^4$ seconds, a maximum $T_{sp} = 78$ dynes/cm², a maximum $P_{sp} = 47$ watts/cm², and a maximum $M_{sp} = 6.5$ micrograms/cm² seconds. For a plasma accelerator with a comparable I_{sp} and a magnetic field of only 10^4 gauss, and operating only 0.1 per cent of the time, the maximum $T_{sp} = 4000$ dynes/cm², the maximum $P_{sp} = 2350$ watts/cm², and the maximum $M_{sp} = 340$ gm/cm² seconds.

P_{sp} represents the power usefully converted. To obtain the efficiency one must take into account all other power required or lost. For the ion drive this includes power radiated by the anode and surrounding structure, power for neutralizing electrons, power to vaporize and ionize the ions, and power lost because of sputtering. For the plasma drive this includes the power to produce the plasma, power radiated by the plasma, power lost in the electrical circuits and so forth. Account must also be taken with each system for any loss of unaccelerated propellant material.

One of the largest power losses for an ion accelerator results from thermal radiation from the anode ion source, the thermionic electron source and nearby heated exposed surfaces. As pointed out earlier, reducing the ion-beam aperture need not reduce the thrust, but it certainly can reduce the amount of exposed anode radiating surface. This reduction will be offset somewhat by the need for a higher anode-surface temperature to provide the increased current density. Consider a 5-mm diameter cesium-ion gun operated at 10 kv. This would require an anode current density of 19 ma/cm² and would give an average voltage gradient of 20 kv/cm, both realistic values. The energy flux in the ion beam would be about 37 watts. For the current density indicated, an anode temperature of about 1400°K would be required. This would radiate about 20 watts/cm² for a total of about four watts. We should expect that the surrounding thermionic electron emitter will contribute at least an equal amount to the radiation flux. Thus, the radiation loss will be at least 20 per cent that of the kinetic energy in the ion beam. This must be considered a lower limit. If one uses larger diameter beams, the same thrust can be obtained, but with a considerably larger radiating anode surface. On the other hand, we may expect conduction from an array of small high-temperature anodes to bring some of the surrounding structure to a high temperature, so that there may well be significant radiation losses from surfaces other than the ion anode and electron cathode.

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[8] E. Stuhlinger and R. Seitz, "Some problems in ionic propulsion systems," IRE TRANS. ON MILITARY ELECTRONICS, vol. MIL-3, pp. 27–33; April, 1959.

[9] G. G. Cloutier and T. W. Johnston, "Charge Neutralization in an Ionic Rocket," RCA Victor Co., Montreal, Que., Canada, Res. Rept. No. 7-811-1; August, 1959.

If we suppose that the neutralizing electron source is a simple emitting surface with no special accelerating electrodes, then the electrons will acquire radial kinetic energy of as much as 1000 ev per electron. If we assume further one electron per ion, the neutralizing electrons will carry away an amount of energy about ten per cent that of the ion beam energy. This energy will not, of course, contribute significantly to the thrust.

Erosion losses are difficult to estimate. The amount of erosion can no doubt be reduced by better ion optics; but this most likely requires a reduction of the total beam current with a corresponding reduction of beam power and over-all efficiency. Let us assume a modest erosion loss of, say, two per cent; that is, we assume that only two per cent of our ions strike the cathode. These collisions will, by sputtering, release an amount of material between five and ten times that of the incident ions. This material will not contribute appreciably to the thrust. We should also add to this one to two per cent of the mass efflux for the loss of un-ionized cesium vapor. The loss of unaccelerated material in effect reduces the specific impulse or thrust of the propellant by at least ten per cent. To compensate for this, the velocity of the ions can be increased one or two per cent, which would require an additional power increment of two to four per cent. Again, this may be an optimistic estimate. The sputtering process will also release electrons, most of which will be drawn to the anode, where they will give up their acquired energy. This can contribute to the anode heating and need not be considered an energy loss.

Some additional power will also be required to vaporize and ionize the cesium, but this should be quite small, less than one per cent. Collecting the more favorable estimates of power loss caused by radiation, neutralization, erosion, and ion production, one obtains an efficiency of between 70 and 75 per cent. A shortcoming of this estimate on over-all efficiency is that to a large extent it presupposes that the various losses cited can be independently minimized. In general, this may not be possible. For example, the electrode configuration that minimizes erosion may also yield a reduced thrust. As a second example, higher current densities may be accompanied by faster destruction of the anode and by greater loss of un-ionized propellant.

In considering the efficiency of a plasma-drive device, we can conveniently divide the problem as follows. How efficiently can the electrical energy be delivered from the storage unit to the plasma acceleration unit, and what fraction of the energy delivered goes to produce useful kinetic energy? Because of the transient nature of the system, an exact analysis is extremely difficult. To transfer energy efficiently from the capacitance storage unit to the plasma acceleration unit, the characteristic impedance of the storage unit and the resistive impedance of the plasma circuit should be comparable. Otherwise, a substantial fraction of the energy will be reflected back into the storage unit and the system will oscillate or ring. Fortunately, an exact matching of impedances is not necessary. Even for a 50 per cent mismatch, about 90 per cent of the energy will be transferred during the first cycle, and additional energy will be transferred in subsequent rings of the system.

All fixed resistance and inductance of the system can be lumped with the capacitor storage parameters. The resistance of the plasma itself is at first largely ohmic in nature and provides the heating necessary to produce and ionize the plasma. This resistance quickly falls with rising plasma temperature. During the acceleration of the plasma, the resistive component results from the rapidly changing inductance of the plasma discharge portion of the circuit. Because the discharge inductance is very small, the impedance ratio in present laboratory systems is low (between 0.01 and 0.1) and there is considerable ringing of the system. By proper design of the total system it should be possible to increase the impedance ratio to over 0.1. Even with a ratio of only 0.1, about 30 per cent of the energy is transferred during each pulse, and about five pulses are required to transfer over 80 per cent of the energy.

Not all of this will go into useful kinetic energy of the plasma. Some of it is required to produce the plasma, and a good portion of it will contribute to heating the plasma and circuit elements. The fraction converted to plasma kinetic energy will depend upon the design of the electrodes and storage unit, and upon the amount and type of plasma. With proper design, well over 70 per cent should go into plasma kinetic energy. Accordingly, we may expect that the over-all conversion of stored electrical energy to plasma kinetic energy should be 50 per cent or better. Indeed, in the plasma thrust experiments mentioned earlier, where the design was far from optimum, efficiencies of over 30 per cent have been obtained.

Specific Impulse and Erosion

For the collinear electrode plasma accelerator, both analysis and experiment indicate that the efficiency and the specific impulse are not affected by the specific thrust. How the efficiency varies with I_{sp} is not certain, but it appears that it should still increase somewhat with increasing I_{sp}. There undoubtedly exists a range of I_{sp} for which the efficiency is near maximum.

In ion drive, the need for a high-temperature ionizing surface limits the range of I_{sp}. At large I_{sp}, because of the voltage-breakdown limitations discussed earlier, an increase in the voltage necessitates roughly an inverse decrease in the voltage gradient. As a result, the ratio of the power in the ion beam to the power radiated varies roughly as the inverse cube of I_{sp}. On the other hand, at low I_{sp}, since the anode-to-cathode spacing cannot be indefinitely reduced, the voltage gradient is proportional to the voltage. Hence, the ratio of beam power to radiated power varies approximately as I_{sp}^5. Thus, the efficiency of an ion accelerator decreases rapidly at both high and low I_{sp}.

A comparable situation for plasma drive would exist if, for example, power were required for a steady-state magnetic field. This, however, can be avoided by a suitable design of plasma accelerator. Thus, the efficiency of a plasma-drive device need not fall with operation at lower specific thrust. Further experiments are needed to determine the efficient ranges of I_{sp} for both ion and plasma devices. It may be added that, because of its intermittent type of operation, a plasma-propulsion unit should operate efficiently over a wide range of thrust.

Erosion presents a particularly serious problem for electrical propulsion devices. In ion drive, erosion can seriously impair the efficiency and reliability of the accelerator.[10] Because of erosion, an accelerating cathode in the form of a grid mesh does not appear very suitable. Good focusing geometry may reduce the erosion to a small amount. However, this may entail an increase in the anode-to-cathode distance with a corresponding decrease in the specific thrust and efficiency.

Erosion need not be as serious a problem for plasma drive. In fact, as shown experimentally with the collinear electrode plasma accelerator, erosion can be employed to provide the major portion, if not all, of the propellant material.

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[10] S. Naiditch, "Experimental Ion Sources for Propulsion," presented at American Rocket Society Meeting, San Diego, Calif., June, 1959, paper no. 833-59.

Comparison of Chemical and Electric Propulsion Systems for Interplanetary Travel*

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Summary—**The basic mission parameters which are required for the evaluation of engine performance for interplanetary flights are defined. The engine parameters are also defined, and the relation between these parameters is formulated. The possibility of achieving much larger payload fractions by the use of electric propulsion systems, as opposed to the use of chemical propulsion systems, is indicated. Methods of calculating impulsive orbit transfers between circular orbits, escape and entry from satellite orbits using low thrust, and optimized powered transfer between heliocentric orbits are given in the Appendix.**

INTRODUCTION

A FUNDAMENTAL problem in present-day space flight is attainment of adequate payload. This problem originates in the limitations of the chemical propulsion systems utilized. In search of methods to circumvent such limitations electric propulsion techniques are presently the object of considerable interest. Historically, improvement in space vehicle performance has come about through increase in propellant specific impulse. Since electric acceleration techniques are known to produce extremely high-particle velocities in related sciences, the extension of such electric techniques into the propulsion field is quite natural. The availability of high specific impulse is not an unmitigated attribute, however, since in electric propulsion techniques the energy required to accelerate the propellant is no longer contained in the propellant itself. Such energy is provided by a solar or nuclear electric supply which, with today's technology, has considerable weight. This weight must be considered in evaluating the gains provided by use of high specific-impulse electric propulsion systems.

The object of this paper is to set forth the basic parameters and to evaluate the capabilities of electric propulsion systems. Comparisons will be drawn with capabilities of conventional chemical systems. This evaluation can best be carried out by considering specific missions. The missions selected for this analysis are the Earth-Mars and the Earth-Venus missions. The engines, as characterized by specific mass, exhaust velocity, mass flow rate, and thrust, will be discussed in the following section. The definition of the mission and its mathematical formulation will be given in the third section. The comparison and evaluation are in the last section. The details of the calculations are given in the Appendix.

The results of such an analysis are important in two ways. First, the mission capabilities of electric propulsion systems being studied can be determined, and second, some guidance in the selection of desirable directions for research can be obtained.

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* Original manuscript received by the IRE, December 21, 1959. Portions of the material in this paper have been obtained through the sponsorship of the Propulsion Lab., Wright Air Dev. Center, Air Res. and Dev. Command, USAF.

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Propulsion System Performance Parameters

The rocket engine operates by ejecting mass. In electric systems, charged particles are accelerated by electric, or electric and magnetic, fields and expelled. The substance expelled is called the propellant. In chemical systems, the expellant is energized by a thermochemical reaction which uses the propellant. If M is the rocket mass, $\dot{M}$ is the time rate of change of rocket mass, $\bar{C}$ is the effective propellant or exhaust velocity relative to the rocket, and $\bar{F}$ is the thrust force due to the rocket engine, then

$$\bar{F} = \dot{M}\bar{C}. \tag{1}$$

The thrust force per unit mass of the rocket, $\bar{f}$, is defined by

$$M\bar{f} = \bar{F}. \tag{2}$$

If $\bar{a}$ is the acceleration vector and if all forces except the thrust force are ignored, it follows from (1) and (2) that

$$M\bar{a} = \dot{M}\bar{C}. \tag{3}$$

It should be noted that $\bar{a} = \bar{f}$ if no other forces are acting. This is the well known rocket equation. For the case where the velocity, direction and rate of propellant flow are constant, (3) can be written as a scalar equation, and integrated immediately to get

$$\Delta v = v_1 - v_0 = C \log \frac{M_0}{M_1}, \tag{4}$$

where the subscripts 0 and 1 refer to the initial and terminal values respectively, v is the velocity, and Δv is called the characteristic velocity. This may be written in terms of the specific impulse I_{sp} as

$$\Delta v = g_0 I_{sp} \log \frac{M_0}{M_1}, \tag{5}$$

where M_0/M_1 is called the mass ratio, and the specific impulse is defined by

$$I_{sp} = \frac{F}{\dot{w}} = \frac{C}{g_0}\cdot \tag{6}$$

Two systems of units are commonly used for defining the specific impulse. In one, F is in pounds force and $\dot{w}$ is in pounds mass per second, and the specific impulse is in pounds force per pounds mass per second. In the other system which will be used here, F is in pounds force and $\dot{w}$ is in pounds weight per second. Although both systems give the same numerical value for the specific impulse, in the second system, the specific impulse is in seconds.

An approximate indication of the terms on which specific impulse can be exchanged for mass flow rate for a given characteristic velocity can be obtained from (5). In general, a slight change in the specific impulse can be balanced only by a large change in the mass ratio. For electric propulsion systems, the specific impulse ranges approximately between 1000 and 20,000 seconds for practical purposes, while for chemical systems, the specific impulse is under 500 seconds. Thus, for a given Δv the electric system requires considerably less propellant mass than a chemical system. Eq. (5) also makes evident that when extremely large Δv's are required, typical of ambitious missions, the use of very high specific-impulse electric systems is the only way by which impossibly large mass ratios can be avoided.

However, the conclusion that the payload is larger for an electric propulsion system than for a chemical propulsion system is not necessarily valid, because for an electric system the mass M_w of the power source and acceleration system is an important factor. The parameter used for this factor is the specific mass which is defined by

$$\alpha = M_w/P, \tag{7}$$

where P is the jet power:

$$P = 1/2(-\dot{M})C^2. \tag{8}$$

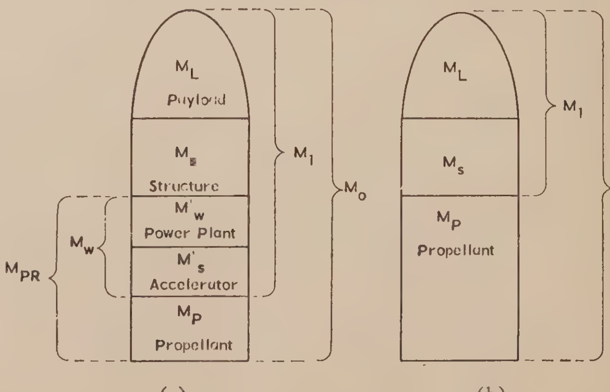
The values of α considered in the literature range from five to fifty kilograms per kilowatt.

A more detailed analysis of a propulsion system is made in the following way. The vehicle is regarded as consisting of two parts. One part is the structure of mass M_s and payload of mass M_L which are independent of the propulsion system. The other part is the propulsion system of mass M_{PR} which consists initially of a power plant of mass M_w', a propellant mass M_p, and a mass M_s' which accounts for the remainder of the propulsion system, including the accelerating device. This last mass is assumed to be proportional to the maximum available thrust and is described by the specific mass

$$\beta = M_s'/F_{\max}. \tag{9}$$

These masses are illustrated in Fig. 1. Also, for this detailed analysis, α' is defined only with reference to the power source; *i.e.*,

$$\alpha' = M_w'/P_e, \tag{10}$$



(a) (b)

Fig. 1—Schematic of vehicle mass distribution. (a) Electric propulsion system. (b) Chemical propulsion system.

where P_e is electrical power output. In addition, the efficiency factors ξ and η are used to bridge the gap between the designer of the electric propulsion system and the mission analyst. The parameter ξ is the proportion of propellant utilized, and the parameter η is the ratio of the directed kinetic energy to the total electric energy input. In these parameters, the total mass of the propulsion system M_{PR} can be represented as

$$M_{PR} = (\alpha' P/\eta) + \frac{1}{\xi}\int_0^T (-\dot{M})dt + \beta F_{\max}, \qquad (11)$$

where P is the jet power and T is the duration of the jet operation. If the rate of mass flow is constant,

$$M_{PR} = (\alpha' P/\eta) - (\dot{M}T/\xi) + \beta F_{\max}. \qquad (12)$$

For the purposes of this paper, it will be assumed that the first and third terms are proportional or that $\beta F_{\max}$ is negligible with respect to (αP). Thus, by (7) the equations corresponding to (11) and (12) are

$$M_{PR} = \alpha P + \int_0^T [-\dot{M}]dt, \qquad (13)$$

and for a constant rate of mass flow

$$M_{PR} = \alpha P + [-\dot{M}]T, \qquad (14)$$

where it is assumed that ξ is set equal to 1.0, its maximum possible value. It should be noted at this point that the terms η, β and ξ which, for convenience in this paper, have been lumped together or assumed to be unity, are actually prime design parameters of electric propulsion devices. The degree to which these parameters are minimized or maximized, as appropriate, is a measure of the excellence of the particular thrust unit considered.

Two additional parameters which describe the vehicle are the payload ratio (M_L/M_0) and the structure factor K. If M_0 is the total initial mass of the vehicle, then K is defined by

$$K = \frac{M_s}{M_0 - M_L}. \qquad (15)$$

For the purposes of this paper, the value of K will be assumed to be 0.05. In terms of the mission and engine parameters, two questions can be asked. First, what is the capability of an electric propulsion system for a given range of values of these parameters, and how do such electric propulsion systems compare with the present and anticipated chemical propulsion systems? Second, for a given mission, what would be desirable values for these parameters?

MISSION DEFINITION

Satellites and probes, both manned and unmanned, can be used for a variety of purposes, *e.g.*, scientific investigation, meteorology, communication relays, and navigation, to mention a few. The first step for any of these is to boost the vehicle into space. This must be done chemically, because the thrust for electric propulsion systems is too low. The second step consists of one or more orbit changes. For some purposes, a third step, landing on Earth or some other body, may be required.

For missions considered in this paper, namely the Earth-Mars and Earth-Venus missions, it will be assumed that the vehicle starts from a circular orbit about the Earth at an altitude of 200 miles. The first class of missions will consist of a transfer from this close-in orbit about Earth to satellite orbits about Mars and Venus. The other class of missions will include the return from the target planet to a 200-mile orbit about Earth. A simplified model will be used. It will be assumed that all the orbits are coplanar and that perturbing forces will be neglected. The mission parameters considered are the duration of the mission and the payload fraction.

Because a particular mission can be accomplished many ways, the problem of optimization arises. Some of the possible objectives are to minimize the total radiation dosage, cost, or take-off weight per unit payload weight. For the above missions, the optimization criterion will be to maximize the payload fraction. The power source will not be considered a part of the payload.

The electric propulsion system considered will be power limited, and it will be assumed that the rate of mass flow, the specific impulse, and the direction of thrust can be regulated, subject only to the power limitation. The use of such an idealized propulsion system is of interest for the following reasons. First, no propulsion system can give a better payload fraction then the idealized system with the same maximum power. This gives an upper bound for the performance of electric propulsion systems. Second, a standard is set which shows how much is lost because of the use of a less flexible propulsion system. This gives some indication as to whether the development of more flexible engines should be considered.

The powered mission will be considered as consisting of two types of maneuvers. One of these will be the escape from or entry into a circular orbit about a planet, and the other will consist of a transfer from the orbit about the sun of the starting planet to the orbit about the sun of the planet which is the objective. The escape or entry maneuver will be regarded as occurring in an inertial frame, *i.e.*, a coordinate system, in which Newton's laws hold, and whose origin is the center of the planet considered. This maneuver will consist of imparting a velocity to the vehicle, starting from a circular orbit about a planet, which is sufficient to enable it to escape from the gravitational influence of that planet. At the termination of this maneuver, it will be assumed that the effect of the gravitational force of the planet is negligible, and that the velocity of the vehicle relative to the planet is zero. For the entry maneuver it will be assumed that the vehicle is at rest, relative to the planet, at a distance at which the gravitational force of the planet is negligible. The second maneuver will be regarded as occurring in an inertial frame whose origin is at the center of the sun. Each maneuver will be considered as occurring in the gravitational field of a single body which is a point mass. Since the mass of each body whose motion is of interest is negligible by comparison with the mass of the body whose field is considered, the field will be considered as a central field, whose center is at the attracting body, and for which the field force per unit mass or acceleration due to gravity is

$$a_r = \frac{-\mu}{r^2}, \tag{16}$$

$$a_\theta = 0, \tag{17}$$

where r and θ are polar coordinates with the origin at the center of the field, a_r and a_θ are the radial and circumferential components of the acceleration, and μ is the numerical value of the acceleration at unit distance from the center of the field. The orbits of Venus, Mars, and Earth were taken as being coplanar and circular with radii which would give the accepted values for their energies. The method of calculation utilized is readily applicable to a much more precise model, which includes perturbing forces, noncircular orbits, etc. However, the comparative capability of electric and chemical propulsion systems can be evaluated from this simplified model and will be adequate for the purposes of this paper.

The performance of chemical propulsion systems will also be calculated using the above model. In addition, it is assumed that the thrust force for the chemical system is impulsive, *i.e.*, that the time integral of the thrust per unit mass is the change in vehicle velocity. This means that the burn-out time is taken as being sufficiently small so that the change in position is negligible during this time. With this assumption, the velocity increment in the direction of thrust due to the propulsion system is given by (4). The velocity increment required will be such that the velocity of the vehicle, after the escape is effectively completed, is the velocity in the transfer orbit. The impulse at the point of intersection of the transfer orbit with the orbit of the target planet will be sufficient to change the orbit of the vehicle from the transfer orbit to the orbit of the target planet, and to place the vehicle in a circular orbit about the target planet. The velocity increment will be used as a measure of the mission requirements for chemical propulsion systems.

For electric propulsion systems, another parameter was suggested as a measure of mission requirements by Irving and Blum,[1,2] in connection with their elegant variational formulation of the thrust-programming problem. By (1) and (2)

$$M^2f^2 = \dot{M}^2C^2,$$

where f and C are the scalar magnitudes of $\bar{f}$ and $\bar{C}$. If this equation is divided by (8) the result may be written

$$-\frac{\dot{M}}{M^2} = \frac{f^2}{2P}.$$

Let M_0 and M_1 be the initial and terminal masses respectively. An integration yields

$$\frac{1}{M_1} - \frac{1}{M_0} = \int_0^T \frac{f^2}{2P}\,dt.$$

Since f and P may be varied independently, M_1, and thus the payload, will be a maximum if P is always as large as possible. For the power-limited engine, this implies that P is fixed at its largest value. Hence

$$\frac{M_1}{M_0} = \left[1 + \frac{M_0}{P}J\right]^{-1}, \tag{18}$$

where

$$J = \frac{1}{2}\int_0^T f^2 dt. \tag{19}$$

The value of J used for a mission is the value obtained for a thrust program which accomplishes the desired mission and maximizes M_1/M_0. In terms of the specific mass, (18) becomes

$$\frac{M_1}{M_0} = \left(1 + \frac{M_0}{M_w}\alpha J\right)^{-1}. \tag{20}$$

Since

$$M_1 = M_L + M_S + M_w, \tag{21}$$

it follows that the payload fraction

$$\frac{M_L}{M_0} = \frac{M_1}{M_0} - \frac{M_w}{M_0} - \frac{M_s}{M_0},$$

or by (20)

$$\frac{M_L}{M_0} = \left(1 + \frac{M_0}{M_w}\alpha J\right)^{-1} - \frac{M_w}{M_0} - \frac{M_s}{M_0}.$$

If the payload fraction is regarded as a function of (M_w/M_0), then a straightforward calculation shows that the payload fraction is a maximum when

$$\frac{M_w}{M_0} = \sqrt{\alpha J} - \alpha J,$$

and the maximum value is

$$\frac{M_L}{M_0} = (1 - \sqrt{\alpha J})^2 - \frac{M_s}{M_0}. \tag{22}$$

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[1] J. H. Irving, "Low-thrust flight: variable exhaust velocity in gravitational fields," in "Space Technology," H. Seifert, Ed., John Wiley and Sons, Inc., New York, N. Y., pp. 10-01 to 10-54; 1959.

[2] J. H. Irving and E. K. Blum, "Comparative Performance of Ballistic and Low-Thrust Vehicles for Flight to Mars," presented at the Second Annual AFOSR Astronautics Symp., Denver, Colo.; April, 1958.

This analysis is valid only for the idealized engine for which the specific mass is independent of the maximum power level. An analogous procedure has been developed for the case where the specific mass is a function of the power level.[3] The evaluation will be based on the assumption that (M_w/M_0) is optimum, thus permitting the use of (22).

To include the effect of the structural factor, (15) is solved for M_s/M_0:

$$\frac{M_s}{M_0} = K\left(1 - \frac{M_L}{M_0}\right), \tag{23}$$

and the result is substituted in (22). Solving the resulting equation for the payload fraction yields

$$\frac{M_L}{M_0} = \frac{(1 - \sqrt{\alpha J})^2 - K}{1 - K} \tag{24}$$

for the electric propulsion system.

For the chemical engine

$$M_1 = M_L + M_s, \tag{25}$$

and by (4)

$$\frac{M_L}{M_0} = \frac{M_1}{M_0} - \frac{M_s}{M_0} = e^{-\Delta v/C} - \frac{M_s}{M_0}.$$

By substituting in this equation the value of M_s/M_0, given by (23), the value of the payload fraction is found to be

$$\frac{M_L}{M_0} = \frac{e^{-\Delta v/C} - K}{1 - K} \tag{26}$$

for the chemical engine. The methods for calculating optimized values for Δv and J for various missions are given in the Appendix.

Summary and Conclusions

The first step in ascertaining the capabilities of chemical propulsion systems is to obtain the minimum velocity increment as a function of trip duration for the mission under consideration. Fig. 2 presents such minimized velocity increments for transfer from a satellite orbit around the Earth to a satellite orbit around the target planet. For all round-trip missions concerned, the unpowered waiting time in a satellite orbit at the target planet is not included in the mission durations shown. The details of the methods of calculation utilized in deriving these data are those shown in the Appendix.

In a similar manner, when electric propulsion systems are considered, minimized values of the acceleration integral J must be derived. Values of J derived for individual mission maneuvers are shown in Fig. 3.

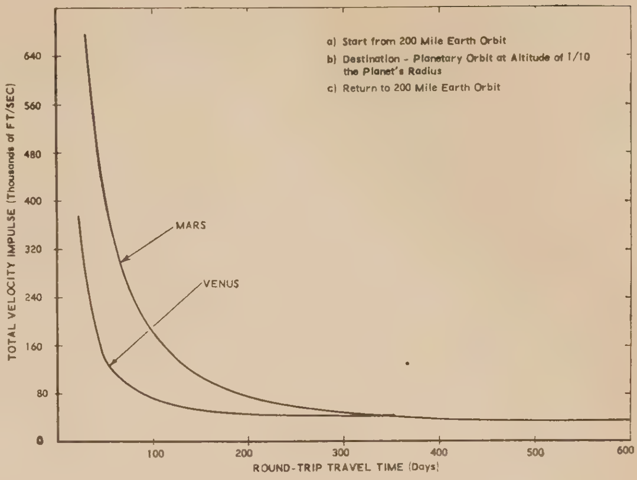

Fig. 2—Total velocity impulse required as a function of round-trip travel time for Mars and Venus missions. 1) Start from 200-mile Earth orbit; 2) Destination, planetary orbit at altitude of 1/10 the planet's radius; 3) return to 200-mile Earth orbit.

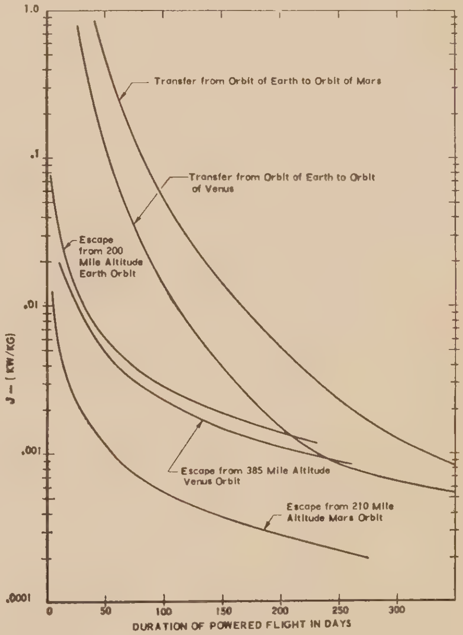

Fig. 3—Values of J required vs duration of powered flight for several maneuvers.

These maneuvers include escape from a 200-mile circular orbit about Earth, escape from circular satellite orbits about Venus and Mars, and transfer from the heliocentric orbit of Earth to the heliocentric orbits of Mars and Venus. The values of J and T, for entry into a satellite orbit, are the same as those for escape, and the mission parameters for transfer between heliocentric orbits are independent of the direction of transfer. Fig. 3 thus provides sufficient information about the various maneuvers which use low-thrust propulsion, so that the requirements for a complete mission may be ascertained. It should be noted that the values of J presented are optimum values for the heliocentric transfers and close to optimum for the planetary escapes and entries. It is also of interest to note that the escape maneuver requirements for J are of the same order of magnitude as the heliocentric transfer requirements.

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[3] "Advanced Space Propulsion Systems, Mission Analysis and Propulsion System Matching," New Devices Labs., Thompson Ramo Wooldridge Inc., Cleveland, Ohio, WADC Tech. Rept. 59-365; July, 1959.

From the results for the individual maneuver the optimized value of J for a complete mission can be obtained; such results are shown in Fig. 4 for escape from an Earth satellite orbit to entry into a satellite orbit about Mars and Venus. The curves drawn are for one-way missions; for an optimized round-trip, the values of J and T are twice those of a one-way trip.

In order to compare the capabilities of electric and chemical propulsion systems, the payload fraction (M_L/M_0) which can be obtained for a given duration T has been chosen as the figure of merit. For chemical systems the payload fraction depends primarily on the specific impulse. For purposes of this paper, specific impulses of 300, 400, 500 and 1000 seconds were selected. A specific impulse of 300 seconds is typical of present-day propulsion systems, while 500 seconds can be regarded as an upper limit. A specific impulse of 1000 seconds can be regarded as possible for thermonuclear propulsion systems which use hydrogen as a propellant. These high specific impulses were chosen to provide a "more-than-fair" consideration of conventional propulsion techniques. It should be pointed out, however, that even if such impulses are attained, doing so at the structural factor (*i.e.*, $K=0.05$) utilized herein is most unlikely.

In considering electric propulsion systems, the specific mass α was used as parameter, and values of α from 5 to 50 kg/kw were considered. The results obtained for several missions are shown in Figs. 5 through 8. It is obvious in these results that electric propulsion systems can provide outstanding mission capabilities for sufficiently low values of α.

A number of points are of interest in these payload fraction figures. First, an important difference is evident between electric and chemical systems. For chemical propulsion the payload fraction improves with increasing mission duration only up to a fixed point; beyond this point an increase in mission time decreases the payload. For electric propulsion, a longer mission always results in a larger payload, although the rate of increase is less for longer times.

Second, it is evident that for equal mission durations electric systems can meet or exceed the performance of 500-second chemical systems. This is even more pronounced for the longer round-trip missions. If somewhat longer durations for the same mission are allowed, the electric system far surpasses the chemical. For example, consider the Earth-Mars round trip in Fig. 7. Powerplant specific masses of 20 kg/kw are certainly feasible today, and such a powerplant roughly equals the payload capability of a 500-second chemical system at its optimum payload time. If the allowed mission duration is increased 50 per cent, the electric system can carry approximately three times more payload than the chemical system. If realistic chemical systems are considered (*i.e.*, 300- to 400-second impulse) they are not at all competitive, nor are chemical systems competitive if optimistic predictions on α are considered. (In the literature, power plant specific masses of 5 kg/kw are presented as feasible in the power range above 10 kw.)

A final point to be considered is the use of the electric power source for purposes other than propulsion, once the destination satellite orbit at a target planet has been established. If this power source is utilized for

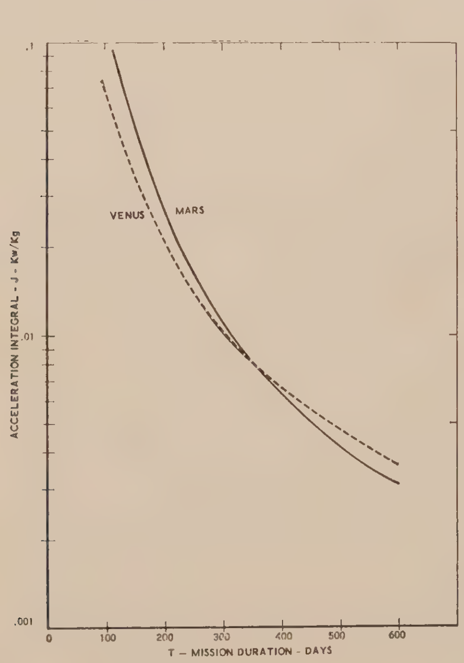

Fig. 4—Total acceleration integral J for an Earth satellite orbit-to-target planet satellite orbit mission, one-way trip.

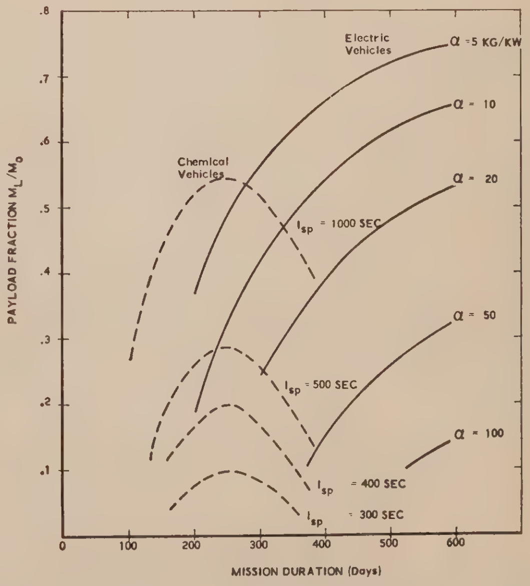

Fig. 5—Comparison of payload capabilities for electric and chemical vehicles on a one-way Mars mission. Structural factor, $K=0.05$.

communication, data processing, etc., it might be fair to include its weight, αP, in the payload fraction rather than in the propulsion system as in the previous figures. The results for such a calculation are given in Fig. 9. The payload fractions shown here compare to the ones previously shown in Fig. 5 for the identical mission. It is evident that such considerations emphasize the desirability of electric propulsion systems.

It should be noted that the acceleration integrals presented in Fig. 3 provide a means for the reader to construct payload capabilities for Venus and Mars missions other than the ones presented herein. For example, by entering a highly elliptical satellite orbit about Venus, an orbit whose eccentricity is nearly one, payload fractions much higher than those shown in Fig. 6 would be obtained. Entry into planetary satellite orbits other than those used in this paper can be determined by computing new J characteristics using the dimensional method of the Appendix.

APPENDIX

Orbits in an Inverse-Square Central Field

The results of this section are required for the calculation of the initial and terminal conditions, as well as the

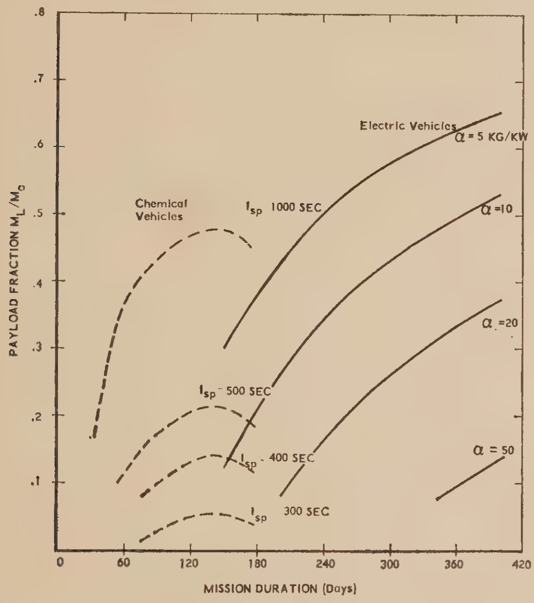

Fig. 6—Comparison of payload capabilities for electric and chemical vehicles on a one-way Venus mission. Structural factor, $K=0.05$.

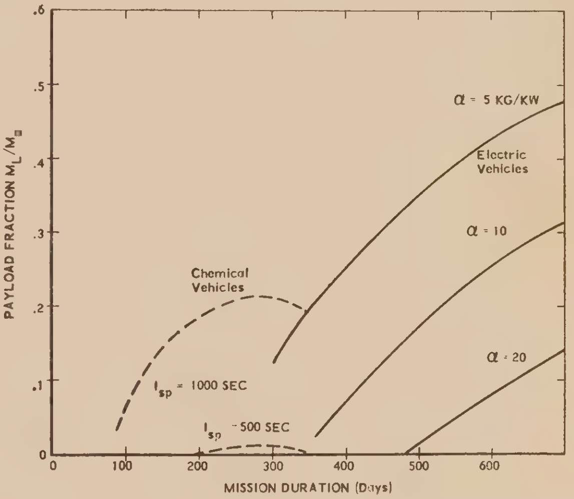

Fig. 8—Comparison of payload capabilities for electric and chemical vehicles on a round-trip Venus mission. Structural factor, $K=0.05$.

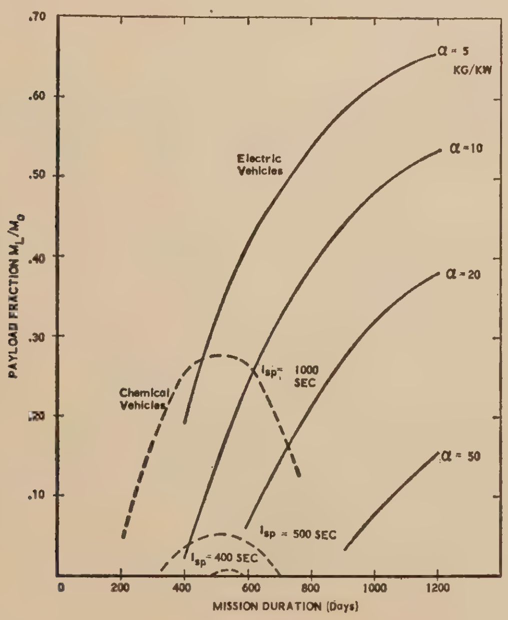

Fig. 7—Comparison of payload capabilities for electric and chemical vehicles on a round-trip Mars mission. Structural factor, $K=0.05$.

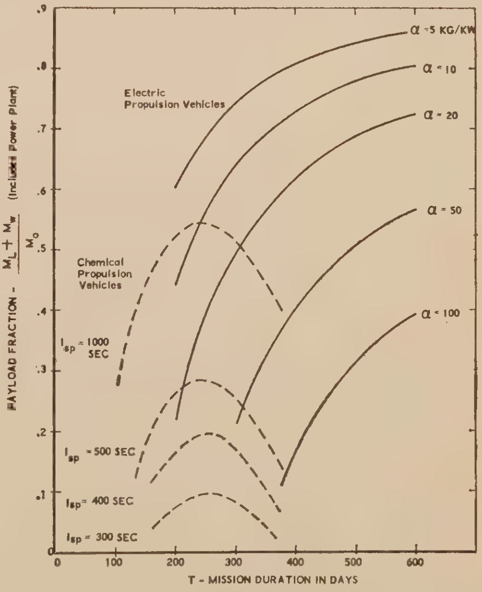

Fig. 9—Comparison of payload capabilities for electric and chemical propulsion vehicles on a one-way Earth-Mars mission where the electric power plant is considered part of the payload.

velocity increment and transfer time for impulsive orbit transfer.

In polar coordinates, the radial and circumferential components of acceleration are

$$a_r = \ddot{r} - r\dot{\theta}^2, \tag{27}$$

$$a_\theta = \frac{1}{r}\frac{d}{dt}(r^2\dot{\theta}). \tag{28}$$

By (16) and (17), the equations of motion for a particle whose mass is small with respect to the central mass are

$$\ddot{r} - r\dot{\theta}^2 = -\frac{\mu}{r^2}, \tag{29}$$

$$\frac{1}{r}\frac{d}{dt}(r^2\dot{\theta}) = 0. \tag{30}$$

Since the angular momentum of the particle per unit mass is defined by

$$h = r^2\theta, \tag{31}$$

(30) can be integrated immediately to yield

$$h = r^2\dot{\theta} = \text{constant}. \tag{32}$$

If (29) is written in the form

$$\ddot{r} - \frac{h^2}{r^3} + \frac{\mu}{r^2} = 0 \tag{33}$$

and multiplied by $\dot{r}$, it can be integrated directly to yield

$$\frac{1}{2}\left(\dot{r}^2 + \frac{h^2}{r^2}\right) - \frac{\mu}{r} = E, \tag{34}$$

where E is a constant of integration. Since the terms on the left are the kinetic and potential energy per unit mass respectively, E is the energy per unit mass, which is constant. Again, by (32)

$$\dot{r} = \frac{dr}{d\theta}\frac{d\theta}{dt} = \frac{h}{r^2}\frac{dr}{d\theta}\cdot$$

Thus, (34) becomes

$$\left(\frac{dr}{d\theta}\right)^2 = \frac{r^4}{h^2}\left[2E + \frac{2\mu}{r} - \left(\frac{h}{r}\right)^2\right].$$

If the reciprocal of the radius is introduced as the dependent variable, this equation can be integrated by separation of variables to yield

$$r = \frac{h^2/\mu}{1 + e\cos(\theta - \theta_0)}, \tag{35}$$

where

$$e^2 = 1 + \frac{2Eh^2}{\mu^2} \tag{36}$$

and θ_0 is a constant of integration. This shows that the trajectory or orbit is a conic section with eccentricity e and focus at the center of the field. For $e=0$, the orbit is a circle; for $0<e<1$, the orbit is an ellipse; for $e=1$, the orbit is a parabola; and for $e>1$, the orbit is a hyperbola.

The velocity v in polar coordinates is given by

$$v^2 = \dot{r}^2 + (r\dot{\theta})^2, \tag{37}$$

and by (34) it is

$$v^2 = 2\left(E + \frac{\mu}{r}\right). \tag{38}$$

A particle is said to have escape velocity v_e if its trajectory is a parabola, *i.e.*, if $e=1$. By (36) this means that $E=0$. Hence, by (38) the escape velocity at a point is

$$v_e = \sqrt{\frac{2\mu}{r}}\cdot \tag{39}$$

For a circular orbit, the circular velocity v_0 is obtained from (33) by noting that $\ddot{r}=0$. Thus the angular momentum h_0 in a circular orbit is

$$\frac{{h_0}^2}{r^3} = \frac{\mu}{r^2},$$

or

$$h_0 = \sqrt{\mu r}. \tag{40}$$

Since the velocity has no radial component,

$$v_0 = r\dot{\theta} = \frac{h_0}{r},$$

and hence

$$v_0 = \sqrt{\frac{\mu}{r}}\cdot \tag{41}$$

It may be noted that (32) can be given another interpretation. The element of area swept out by a vector from the origin to the particle is

$$dA = \frac{1}{2}r^2 d\theta,$$

and hence

$$\frac{dA}{dt} = \frac{1}{2}h\cdot \tag{42}$$

For elliptic orbits several parameters will be considered. The length a of the semimajor axis is half the sum of the minimum and maximum distances from the center of the field to the orbit. These distances are given when $\cos(\theta-\theta_0)$ assumes the values 1 and -1 respectively. Thus, by (35)

$$a = \frac{h^2}{2\mu}\left(\frac{1}{1+e} + \frac{1}{1-e}\right) = \frac{h^2}{\mu(1-e^2)}\cdot \tag{43}$$

The length b of the semiminor axis is given by

$$b^2 = a^2(1 - e^2) = \frac{h^4}{\mu^2(1 - e^2)} \cdot \tag{44}$$

Since the area of an ellipse is πab, the period τ of a particle in an elliptic orbit is obtained by integrating (42). This gives

$$\tau = \frac{2A}{h} = \frac{2\pi ab}{h} = 2\pi\left(\frac{a^3}{\mu}\right)^{1/2} . \tag{45}$$

The mean angular velocity m is

$$m = \frac{2\pi}{\tau} = \left(\frac{\mu}{a^3}\right)^{1/2} . \tag{46}$$

In cartesian coordinates with the x axis parallel to the major axis and the origin at the midpoint of the major axis, the parametric equations of the ellipse are

$$x = a \cos \phi,$$
$$y = b \sin \phi, \tag{47}$$

where ϕ is the angle between the x axis and the vector from the origin of the cartesian coordinates to the particle. By considering the areas swept out by the radius vectors in both coordinate systems, the time t, required for the particle to move from a point closest to the center of the field to another point on its orbit, can be seen to be

$$mt = \phi - e \sin \phi. \tag{48}$$

The time of transit between any two points of the trajectory can be computed by using this formula two times. A similar formula using hyperbolic functions can be obtained for hyperbolic orbits. If (36) is solved for E, a comparison with (43) yields

$$E = -\frac{\mu}{2a} \cdot \tag{49}$$

This equation also holds for hyperbolic orbits provided a is allowed to assume negative values.

Impulsive Orbit-Transfer Between Circular Orbits

To change orbits impulsively at a point requires that the particle velocity $\bar{v}_0$ in the first orbit be changed impulsively to the velocity $\bar{v}_1$ required in the second orbit. Let E_0, h_0, and E_1, h_1, be the energies and angular momenta per unit mass in the first and second orbits respectively. Since no work is done by the field forces in an impulsive change of velocity, the work done which equals the change in kinetic energy is

$$\Delta E = E_1 - E_0 = \tfrac{1}{2}(v_1^2 - v_0^2) = \tfrac{1}{2}(\bar{v}_1 - \bar{v}_0)\cdot(\bar{v}_1 + \bar{v}_0). \tag{50}$$

If the velocity increment required is denoted by

$$\Delta\bar{v} = \bar{v}_1 - \bar{v}_0, \tag{51}$$

then

$$\Delta E = \tfrac{1}{2}\Delta\bar{v}\cdot(\bar{v}_0 + \bar{v}_1),$$

or

$$\Delta E = \tfrac{1}{2}(\Delta v)^2 + \bar{v}_0\cdot\Delta\bar{v}. \tag{52}$$

If the initial orbit is a circle, the angular momentum in the second orbit is the product of the radius and the component of $\bar{v}_1$ in the direction of $\bar{v}_0$, *i.e.*,

$$\Delta h = h_1 - h_0 = r\left(\bar{v}_1\cdot\frac{\bar{v}_0}{v_0} - \bar{v}_0\cdot\frac{\bar{v}_0}{v_0}\right),$$

or

$$\Delta h = r\left(\Delta\bar{v}\cdot\frac{\bar{v}_0}{v_0}\right);$$

hence

$$\Delta\bar{v}\cdot\bar{v}_0 = \frac{v_0\Delta h}{r} \cdot \tag{53}$$

Substituting for the last term in (52) yields

$$\Delta E = \frac{1}{2}(\Delta v)^2 + \frac{v_0\Delta h}{r} \cdot$$

This can be written

$$\left(\frac{\Delta v}{v_0}\right)^2 = \frac{2\Delta E}{v_0^2} - \frac{2\Delta h}{rv_0} \cdot \tag{54}$$

By (38) and (41) the energy per unit mass in a circular orbit is

$$E_0 = \frac{1}{2}v_0^2 - \frac{\mu}{r} = -\frac{1}{2}v_0^2,$$

and the angular momentum per unit mass in a circular orbit is

$$h_0 = rv_0.$$

Thus

$$\left(\frac{\Delta v}{v_0}\right)^2 = -\left(\frac{\Delta E}{E_0} + 2\frac{\Delta h}{h_0}\right). \tag{55}$$

This Δv is to be identified with the Δv in (4), under the assumption of negligible burn-out time. By changing the sign of the right side of (55), the velocity increment required to change from an arbitrary orbit to a circular orbit is obtained.

To illustrate the use of these formulas, the velocity increments needed for a Hohmann transfer orbit between the heliocentric orbit of Earth and the heliocentric orbit of Mars will be computed. The Hohmann transfer orbit is an ellipse which is tangent to the two circular orbits. Let r_e and r_m be the radii of Earth's and Mars' orbits, respectively, and let μ_s be the strength of the gravitational field of the Sun. The major semiaxis of the transfer orbit is

$$a = \tfrac{1}{2}(r_e + r_m). \tag{56}$$

By (49) the energy per unit mass of the transfer orbit is

$$E_r = -\frac{\mu}{r_e + r_m}\cdot$$

Since the velocity of the transfer orbit and the velocity of the initial orbit are parallel, $\bar{v}_0 \cdot \Delta\bar{v} = v_0 \Delta v$, and (52) becomes

$$\Delta E = \tfrac{1}{2}(\Delta v)^2 + v_0(\Delta v).$$

Hence

$$\frac{\Delta v}{v_0} = -1 + \sqrt{1 + \frac{\Delta E}{\frac{1}{2}v_0^2}}\cdot$$

But

$$\Delta E = -\frac{\mu_s}{2}\left(\frac{2}{r_e + r_m} - \frac{1}{r_e}\right)$$

$$v_0^2 = \frac{\mu_s}{r_e}\cdot$$

Thus,

$$\frac{\Delta v}{v_e} = -1 + \sqrt{\frac{2(r_m/r_e)}{1 + (r_m/r_e)}}\cdot \qquad (57)$$

A similar calculation for the transfer to the Mars' orbit yields

$$\frac{\Delta v'}{v_m} = 1 - \sqrt{\frac{2}{1 + (r_m/r_e)}}\cdot \qquad (58)$$

The escape from the satellite orbit about Earth and the transfer from the heliocentric Earth's orbit to the Hohmann orbit can be combined in the following way. It is assumed that the velocity imparted to the vehicle in the field of Earth is such that when the vehicle has effectively escaped, *i.e.*, when the potential energy of Earth's field is negligible, the remaining velocity is the velocity increment Δv required for the transfer to the Hohmann orbit. The energy of the vehicle, relative to Earth, will be $\frac{1}{2}(\Delta v)^2$, and the velocity v which the vehicle must have is, by (38),

$$v^2 = 2\left[\frac{1}{2}(\Delta v)^2 + \frac{\mu_e}{r_{oe}}\right],$$

where μ_e is strength of Earth's field, and r_{oe} is the radius of the circular satellite orbit about Earth. If v_{se} is the escape velocity from the orbit in Earth's field, then by (39) the required velocity is

$$v^2 = (\Delta v)^2 + v_{se}^2. \qquad (59)$$

The vehicle has a velocity in the circular satellite orbit about Earth, which by (39) and (41), is $v_{se}/\sqrt{2}$. Hence, the total velocity increment Δv_e, required for escape from the close-in orbit and transfer to the Hohmann orbit, is

$$\Delta v_e = \sqrt{(\Delta v)^2 + v_{se}^2} - \frac{v_{se}}{\sqrt{2}}\cdot \qquad (60)$$

For the transfer from the Hohmann orbit to the heliocentric Mars' orbit and entry into a circular satellite orbit about Mars, the velocity increment Δv_m required is

$$\Delta v_m = \sqrt{(\Delta v')^2 + v_{sm}^2} - \frac{v_{sm}}{\sqrt{2}}\cdot \qquad (61)$$

The total velocity increment Δv_T required for the mission is:

$$\Delta v_T = \Delta v_e + \Delta v_m. \qquad (62)$$

The time T required will be half of the period of the Hohmann orbit which is by (45) and (56)

$$T = \frac{\pi}{2}\left[\frac{(r_e + r_m)^3}{2\mu_s}\right]^{1/2}\cdot \qquad (63)$$

For other transfer orbits (48) is used.

The value of Δv_T used for a given T is the smallest possible value. This was obtained by computing Δv_T as a function of T for several values of the transit angle. The envelope of this family of curves gave the minimum Δv_T for a given T. The time spent in satellite orbit about Mars and Venus is not included in these calculations. For round trips, Δv_T and T were doubled.

Escape and Entry Using Low Thrust

Studies made by Lawden,[4] Benney,[5] Tsien,[6] and Irving[1] indicate that constant circumferential thrust per unit mass is very close to optimum, and constant tangential thrust per unit mass is nearly as close to optimum. The figures used for escape from earth are those obtained by Irving and Blum.[2] For a mission starting from a close-in orbit about the earth, and ending in a close-in orbit about the target planet, the value of J is the sum of the values of J for the individual maneuvers. Since there are no dissipative terms, the reversal of the thrust program for escape gives the thrust program for entry. From the graph of J_e as a function of T_e, the thrust acceleration f can be computed from

$$J_e = \tfrac{1}{2}\int_0^{T_e} f^2 dt = \tfrac{1}{2}T_e f^2. \qquad (64)$$

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[4] D. F. Lawden, "Optimal escape from a circular orbit," *Astronaut. Acta*, vol. 4, no. 3, pp. 218–233; 1958.

[5] D. J. Benney, "Escape from a circular orbit using tangential thrust," *Jet Propulsion*, vol. 28, pp. 167–169; March, 1958.

[6] H. S. Tsien, "Takeoff from satellite orbit," *ARS Journal*, vol. 23, pp. 233–236; July–August, 1953.

The equations of motion for constant tangential thrust per unit mass are

$$\ddot{r} - \frac{h^2}{r^3} + \frac{\mu}{r^2} = \frac{f\dot{r}}{v}, \tag{65}$$

$$\frac{1}{r}\frac{dh}{dt} = \frac{fh}{rv}, \tag{66}$$

where

$$v = \sqrt{\dot{r}^2 + \left(\frac{h}{r}\right)^2}. \tag{67}$$

The initial conditions are those for a circular orbit:

$$t = 0, \qquad r = r_0, \qquad \dot{r} = 0, \qquad h = \sqrt{\mu r_0}. \tag{68}$$

At $t = T_e$ the terminal condition is

$$E = E_1 = \tfrac{1}{2}\left[\dot{r}_1^2 + \left(\frac{h_1}{r_1}\right)^2\right] - \frac{\mu}{r_1} = 0, \tag{69}$$

where the subscript 1 refers to the values at escape. The solution of this problem is obtained by integrating the equations of motion numerically, and monitoring the value of the energy.

If the radius of the circular orbit is taken as unity and the period in the circular orbit is taken as the unit of time, the value of μ is, by (45),

$$\mu = 4\pi^2.$$

The initial conditions become at $t = 0$

$$r_0 = 1, \qquad \dot{r}_0 = 0, \qquad h_0 = 2\pi,$$

and the terminal condition remains $E_1 = 0$. The equations of motion retain their form. In these units,

$$J_e = J_e(T_e) \tag{70}$$

is independent of the radius of the initial circular orbit, as well as the strength of the central field; hence, the solution for escape from Earth can be used to give the escape or entry from or into a circular orbit, using constant tangential thrust per unit mass, for any central field. A direct calculation yields

$$J_m = \sqrt{\left(\frac{g_{om}}{g_{oe}}\right)^3 \left(\frac{r_{om}}{r_{oe}}\right)} J_e, \tag{71}$$

$$T_m = \sqrt{\left(\frac{r_{om}}{r_{oe}}\right)\left(\frac{g_{oe}}{g_{om}}\right)} T_e, \tag{72}$$

$$J_v = \sqrt{\left(\frac{g_{ov}}{g_{oe}}\right)^3 \left(\frac{r_{ov}}{r_{oe}}\right)} J_e, \tag{73}$$

$$T_v = \sqrt{\left(\frac{r_{ov}}{r_{oe}}\right)\left(\frac{g_{oe}}{g_{ov}}\right)} T_e, \tag{74}$$

where T_e, T_m, and T_v are the escape times; J_e, J_m, and J_v are the values of one-half the integral of the square of the thrust per unit mass; g_{oe}, g_{om}, and g_{ov} are the accelerations due to gravity at the orbits around the planets; and r_{oe}, r_{om}, and r_{ov} are the radii of the initial orbits about Earth, Mars, and Venus, respectively. Since the altitude of the Earth orbit is 200 miles and the other orbits are at altitudes of one-tenth of the radii of the planets, the above formulas become

$$\left.\begin{aligned} J_m &= 0.154 J_e \\ T_m &= 1.265 T_e \\ J_v &= 0.708 J_e \\ T_v &= 1.136 T_e \end{aligned}\right\}. \tag{75}$$

The Approximation of J for Interplanetary Orbit Transfer

The calculation of J requires the determination of that trajectory

$$r = r(t), \tag{76}$$

$$h = h(t), \tag{77}$$

which makes

$$J = 1/2 \int_0^T f^2 dt \tag{78}$$

a minimum, where

$$f^2 = f_r^2 + f_\theta^2, \tag{79}$$

$$f_r = \ddot{r} - \frac{h^2}{r^3} + \frac{\mu}{r^2}, \tag{80}$$

$$f_\theta = \frac{1}{r}\frac{dh}{dt}, \tag{81}$$

and, by (40),

$$\left.\begin{aligned} r(0) &= r_0 \\ \dot{r}(0) &= 0 \\ h(0) &= \sqrt{\mu r_0} \\ r(T) &= r_1 \\ \dot{r}(T) &= 0 \\ h(T) &= \sqrt{\mu r_1} \end{aligned}\right\}. \tag{82}$$

The conditions give the requirements for transfer in a central field from a circular orbit of radius r_0 to a circular orbit of radius r_1. Although the calculations have been formulated for the field due to a single body, this formulation can be extended to include the gravitational forces exerted by several bodies and other perturbing forces, as well as transfer between noncoplanar orbits. The transit angle can also be prescribed. In the form given above, the problem is a classical problem of the calculus of variations, and the Euler variational equations are a sixth-order system of nonlinear, ordinary differential equations. Some integrals have been obtained by Irving and Blum, but the solutions can be obtained only by numerical integration. This requires a trial and error process for determining three additional initial conditions, for which the particular solutions have the desired terminal values. In these calculations, the terminal conditions must be satisfied very closely, or large errors will result in the values of J obtained. Studies have indicated that J is extremely sensitive to terminal conditions.

The method used in this paper for the minimization of J is a direct method analogous to the Rayleigh-Ritz method. A family of trajectories which exactly satisfies the initial and terminal conditions is used, and J is minimized with respect to this family by a gradient method. Results obtained on a medium-size digital computer using this method have shown this procedure to be much more efficient and accurate than use of the Euler equations. The details of the method and the error analysis will be given elsewhere.[7]

The values of J and the transfer time selected for the total specified mission time T are those values for which the sum of the J's for the separate maneuvers is a minimum. This sum was obtained by first determining J_T+J_e as a function of T_e for various values of the parameter (T_e+T_T) where the subscripts e and T refer to Earth escape and heliocentric transfer from the Earth's orbit to Mars' orbit respectively. The minimum values of (J_T+J_e) for various fixed values of (T_e+T_T) were used in the same way with the Mars escape curve of J_m as a function of T_m to determine the minimum of $(J_e+J_T+J_m)$, for a fixed value of $(T_e+T_T+T_m)$. Similar calculations were made for the Venus trip. For round trips, the values of J and T were doubled.

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[7] C. Saltzer, "A variational method of determining optimum thrust program to accomplish coplanar orbit transfer," unpublished; 1959.

Electrostatic Propulsion*

STAFF OF THE RAMO-WOOLDRIDGE RESEARCH LABORATORY†

Summary—**The thrust (newtons) developed by a system which accelerates a space charge limited flow of ions of specific charge q/m (coulombs per kilogram) through a voltage V is given by $F=(2\pi/q)\epsilon_0 V^2R^2=\sqrt{2m/q}\,V^2P$. R is an aspect ratio of ion beam diameter to acceleration distance x_0, and P is a diode perveance (amp/volts$^{3/2}$). Lines of electric force extend from charges in transit across the diode to charged surfaces of the accelerator electrode, on which the thrust is thus purely electrostatic. Alkali metals have favorable characteristics for use as propellants because their ions can be produced for small energy expenditure near 100 electron-volts per ion by surface contact ionization, while porous tungsten with pore size less than one micron is an efficient and convenient emitting surface. For practical values of thrust ($F>0.01$ lbf$=2.25\times10^{-3}$ newtons) and specific impulse ($I_{sp}>2000$ seconds) alkali metal thrust devices will operate at a few kilovolts and require $R\gg1$. But for $R\gtrsim3$, unipolar ion beams will reverse their direction of flow within a few x_0. Mathematical solutions to the neutralization problem for the case of one-dimensional flow of mixed ion and electron beams are presented assuming no energy exchanges by collisions or plasma instabilities. These show a periodic spatial potential distribution of wavelengths 0.027 x_0 for cesium, corresponding to time fluctuations of the potential at the plasma oscillation frequency in a frame of reference moving with the ions. Electrons having a Maxwellian distribution of velocity at 1000°K have an average velocity much faster than the ions, and for this case it appears that no time independent solution exists. The injection of electrons from strips spaced 2d apart and placed edgewise in the beam is analyzed under the hopeful assumption that there are no potential fluctuations along the direction of ionic motion. Electrons oscillate transversely across this direction in a potential trough having a depth midway between the cathode strips equal to $2V_0d^2/9x_0^2$. The electron current density is $75d/x_0$ times greater than the cesium ion current density. It is concluded that numerous closely-spaced electron injectors must be used, and that the total electron circulating current must be orders of magnitude greater than the ion current. Finally, if particles having much smaller specific charge than elemental ions could be copiously produced and accelerated, practically useful thrusts could be gained from pencil beam at $R\approx1$. The complications of neutralization would then probably be eliminated.**

THE electrostatic thrust engine in its simplest form is a diode in which charged particles emitted by one electrode are accelerated and transmitted by another into space. If a voltage is applied in the absence of charged particle emission there is no current, no work is done, no power is required to maintain the potential difference, the electrostatic forces on the electrodes are equal and opposite, and there is no thrust. When we cause a current of ions to flow and be accelerated across a potential drop, power is expended and a thrust is exerted equal to the rate of change of momentum of the ions. The forces on the electrodes can no longer be equal and opposite; the detailed manner in which the unbalance occurs is shown by Fig. 1 and the equations which define space-charge-limited flow. For one-dimensional flow these are Poisson's equation,

$$\frac{d^2V}{dx^2}=-\frac{\rho}{\epsilon_0}, \tag{1}$$

the conservation of energy,

$$qV=\tfrac{1}{2}mv^2, \qquad \text{i.e., } v=\sqrt{2qV/m}, \tag{2}$$

and the equation of continuity,

$$J=nqv=\text{constant for all } x. \tag{3}$$

(MKS units will be used and the symbols are defined at the end of the paper.)

These lead to the familiar Child's Law,

$$J=\frac{4}{9}\epsilon_0\sqrt{\frac{2q}{m}}\,\frac{V^{3/2}}{x^2}. \tag{4}$$

The conservation of momentum defines the thrust per unit area,

$$\frac{F}{A}=\dot{M}v=Jvm/q \tag{5}$$

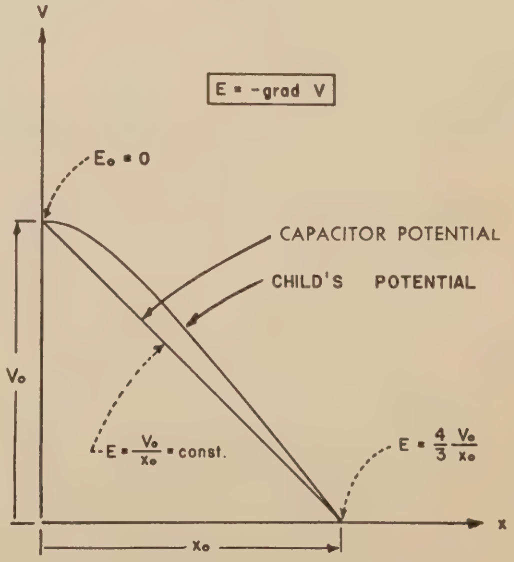

Fig. 1—The potential distribution in a parallel plane diode with and without space-charge-limited current flow.

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* Original manuscript received by the IRE, December 14, 1959; revised manuscript received, December 30, 1959. A portion of the research reported in this paper was sponsored by the Propulsion Lab., Wright Air Dev. Ctr., Air Res. and Dev. Command, U. S. Air Force, under Contract No. AF33(616)-5919.

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which can be combined with the preceding equation to yield,

$$\frac{F}{A} = \frac{8}{9}\epsilon_0 \frac{V^2}{x^2}. \tag{6}$$

This last expression, except for a numerical factor of 16/9, is the electrostatic force per unit area on either plate of a parallel-plate capacitor,

$$\left(\frac{F}{A}\right)_{\text{capacitor}} = \frac{1}{2}\epsilon_0 \frac{V^2}{x^2}.$$

Both the factor of 16/9 and the presence of an unbalanced force on one electrode are consequences of the nonuniform field along the direction of current flow. Fig. 1 compares the linear potential distribution across a capacitor with the curve distribution for space-charge-limited flow. The former has a constant gradient $E = -V_0/x_0$, but the field for Child's potential has a space dependence,

$$E(x) = -\frac{4}{3}\frac{V_0}{x_0}\left(\frac{x}{x_0}\right)^{1/3}.$$

The field is zero at the emitting electrode but is 4/3 stronger than a uniform field at the accelerating electrode,

$$E_{x=x_0} = -\frac{4}{3}\frac{V_0}{x_0}.$$

On squaring these fields, we find no force on the emitting electrode and the factor of 16/9 noted above in the force on the accelerating electrode. The thrust per unit area is simply an electric stress on an electrode caused by lines of force which terminate on the charged surface. At the other ends these lines terminate on space charge in transit. The thrust on an electric rocket is thus found by integrating the electrostatic pressures on the charged surfaces of its engine, in close analogy to the manner in which the thrust on a chemical rocket may be found from a complete inventory of pressure forces over the surfaces of its combustion chamber and nozzle.

ASPECT RATIO AND PERVEANCE

Eq. (6) can be put into the form,

$$F = \frac{8}{9}\epsilon_0 V^2 \frac{A}{x_0{}^2} = \frac{2\pi}{9}\epsilon_0 V^2\left(\frac{D}{x}\right)^2 = \frac{2\pi}{9}\epsilon_0 V^2 R^2, \tag{7}$$

where $R = D/x_0$ is the "aspect ratio" of the diode. D is the diameter of a circle having the same area as the emitting region of the diode, and x_0 is the acceleration distance, *i.e.*, the diode spacing.

The total thrust of a space-charge-limited electrostatic system is therefore a function only of the total voltage and the aspect ratio of the beam. The relationships are shown in Fig. 2. While the total thrust is the same for all charge-to-mass ratios for a given V and R, the specific impulse (*i.e.*, the exit velocity)[1] is not. The latter must usually be set at a value which will meet requirements of optimum rocket performance. For an ion of given q/m, the voltage V is therefore fixed by considerations of the rocket mission and the power supply, as discussed elsewhere [1]. The value of the aspect ratio R is then determined by the required total thrust.

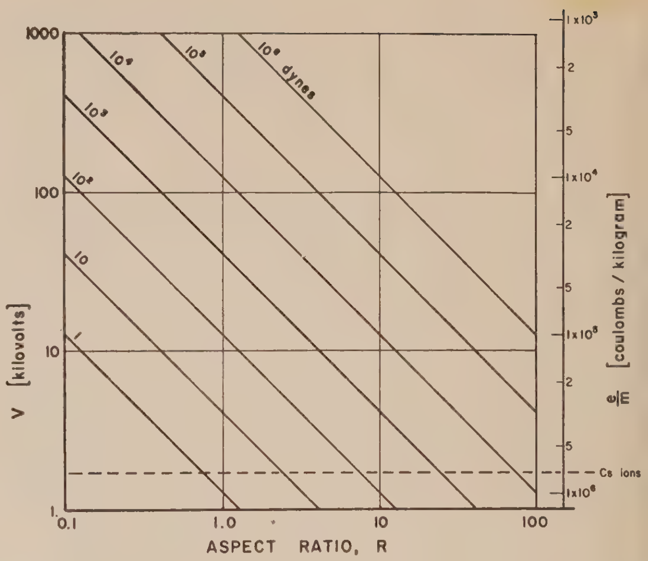

Fig. 2—Thrust as a function of the aspect ratio and the acceleration voltage. The number accompanying each line is the delivered thrust in dynes. The scale at the right indicates the correct acceleration voltage for a specific impulse of 5000 seconds for a given charge-to-mass ratio in the particles to be accelerated. A dashed line indicates that for Cs ions ($e/m = 7.5 \times 10^5$ coulombs per kilogram) an acceleration voltage of ~1.7 kilovolts is desired for a specific impulse of 5000 seconds.

The aspect ratio is closely related to the perveance, a familiar vacuum tube parameter defined as follows:

$$P \equiv I/V^{3/2} \text{ amps/(volts)}^{3/2}.$$

For a space-charge-limited diode,

$$P = \frac{\pi}{9}\epsilon_0\sqrt{\frac{2q}{m}}\,R^2 \begin{array}{l} = 1.83 \times 10^{-6} R^2 \text{ for electrons,} \\ = 0.37 \times 10^{-8} R^2 \text{ for Cs ions.} \end{array} \tag{8}$$

This equation relates the purely electrical quantity P to the geometrical parameter R. While an ionic thrust device will seldom, if ever, actually have a plane parallel configuration, the aspect ratio provides a basis for comparison of any system having a known perveance with an equivalent plane diode. R is, specifically, the ratio of diameter to spacing of a circular plane diode which would have the same perveance as the system under consideration. Implicit in this definition is the fact that for the same q/m all space-charge-limited diodes of a given shape have the same perveance regardless of their actual size.

As discussed in a later section, ions in a broad beam injected into free space will come to rest and reverse their motion within a distance approximately equal to the spacing of the equivalent diode. This spacing is thus effectively the "turn-around distance," and is a property of any monoenergetic ion beam in which motion and potential variation occur only along a single direction. The aspect ratio may thus be regarded as the ratio of beam diameter to turn-around distance, and is a useful parameter in discussions of charge neutralization. It should be noted that when a beam is expanded the diameter and the turn-around distance increase in proportion, so that R is invariant.

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[1] Specific impulse equals exhaust velocity divided by the acceleration of gravity.

It is apparent from (7) and Fig. 2 that $R \gg 1$ for almost any practical ionic thrust system using alkali ions. On the other hand, $R<1$ for most ion and electron beams encountered in practice. For example, a cathode ray beam with a current of 1 milliampere at 10,000 volts has an aspect ratio of about 1/40. For a thrust of 0.001 pound, using 1000 volt ions, $R=25$ (ion velocity = 37 km/second for cesium, specific impulse = 3800 seconds, current = 0.084 ampere).

PRODUCTION OF IONS

The optimum exit velocity for an ionic propulsion system requires accelerating voltages ranging from a few kilovolts down to less than 1000 volts for some applications, provided singly charged elemental ions are used [1]. If high propulsive efficiencies are to be obtained, the power expended in forming an ion must be a small fraction of that required to accelerate it. An ion source with an energy consumption prior to acceleration of about 100 electron volts per ion, or less, is therefore desired. Values in this range have been experimentally obtained from the ionization of alkali metals on hot surfaces of high work function [2]. While encouraging efficiencies from gas discharge devices have also been reported [3], only surface ionization of the alkalis is discussed below.

The phenomena of surface ionization were studied in early classic experiments [4], [8] by placing a hot tungsten filament in a region filled with the vapor of an alkali metal. If the surface work function is higher than the ionization potential of the alkali atoms, the atoms lose an electron to the tungsten when they are adsorbed. After a period of residence on the surface, they evaporate as positive ions if the applied electric field permits. If the work function becomes lower than the ionization potential, the ionization process is much less effective and most of the alkali evaporates as neutral atoms. Since the effect of adsorbed alkali is to reduce the work function of tungsten, the ion-emitting state can be maintained only when the tungsten surface is slightly covered (less than about ½ per cent) with adsorbed alkali. Below this degree of surface coverage, the rate of ion evaporation is almost exactly equal to the rate of arrival of atoms from the vapor. The rate of ion emission will rise in exact proportion to the arrival rate if the vapor pressure is increased, but the surface coverage on the tungsten will also rise. If pushed too far, this effect will lower the work function too much. For a given tungsten temperature, there is thus a maximum ion-emission current density. Attempts to increase the current beyond this point, or to reduce the temperature, cause the surface to change to the atom-emitting condition. We denote by T_c the critical temperature in degrees Kelvin at which the transition between the predominantly atom-emitting and ion-emitting conditions occurs. The tungsten temperatures required for ion current densities J amperes/cm² were found by early workers in this field [4] [8] to be as follows:

For

$$\begin{aligned} &\text{cesium,} && \log_{10} J = 8.99 - 14{,}350/T_c; \\ &\text{rubidium,} && \log_{10} J = 9.15 - 15{,}700/T_c; \\ &\text{potassium,} && \log_{10} J = 6.37 - 11{,}300/T_c. \end{aligned} \tag{9}$$

Numerical values based upon these equations are tabulated in Langmuir [5], [6].

The energy consumption consists almost entirely of losses caused by thermal radiation and this increases much more slowly than the ion current as T_c is raised. The efficiency of ionization therefore improves at higher current densities. In references cited above measurements up to 0.002 ampere/cm² for cesium and somewhat less for potassium and rubidium are reported. The ionization energy requirement for cesium at this current density is about 1000 ev/ion. While extrapolation of (9) indicated that the energy consumption might be as low as 45 ev/ion at 0.1 ampere/cm², no actual experimental data were available. It was of interest to know whether such high-current densities could, in fact, be drawn with high ion-to-atom ratios, and also whether the efficiencies would be as predicted by extrapolation.

Direct measurements at high-current densities have been reported by Shelton, Wuerker, and Sellen [2]. The tungsten was a filament 0.002 inch in diameter, and the collectors consisted of three coaxial cylinders 2 mm in diameter.

Fig. 3 shows how the current density of emitted ions varied as the filament temperature is raised through the critical temperature. Fig. 4 shows the current variation with voltage for potassium ions. The result is a typical diode characteristic. Relatively high voltages and small spacings were required to overcome the space-charge current of massive ions, and the saturation is limited by vapor pressure (*i.e.*, the rate of arrival), not by surface temperature. In Fig. 5 the saturation current density, that is, the density in the presence of an excess of voltage and with tungsten temperature higher than T_c, is plotted vs the equilibrium vapor temperature. One can see that cesium, rubidium, and potassium ion current densities above 100 ma/cm² were achieved, and that the results are in good agreement with those expected from the known vapor pressures of the alkalis.

These results confirm that the ion-emitting properties of the tungsten surface which had been observed at

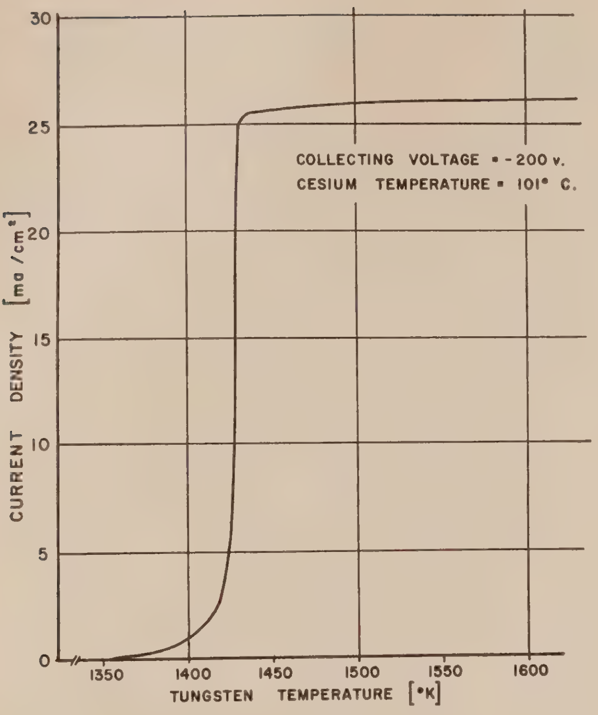


Fig. 3—The positive ion current emitted by a tungsten filament immersed in cesium vapor as the tungsten temperature is raised, showing the sharp transition from predominantly atom-emitting to ion-emitting condition at a critical temperature [2].

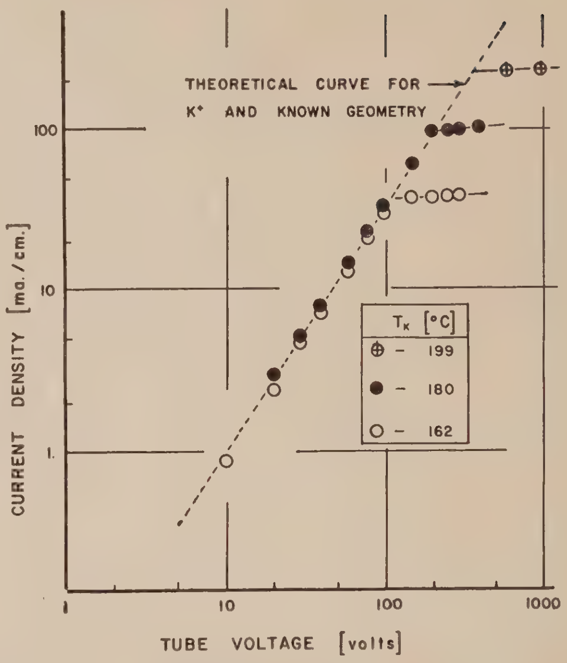


Fig. 4—Space-charge-limited behavior of potassium ions emitted by a tungsten filament immersed in potassium vapor. The tungsten was maintained at a temperature higher than the critical temperature T_c [2].

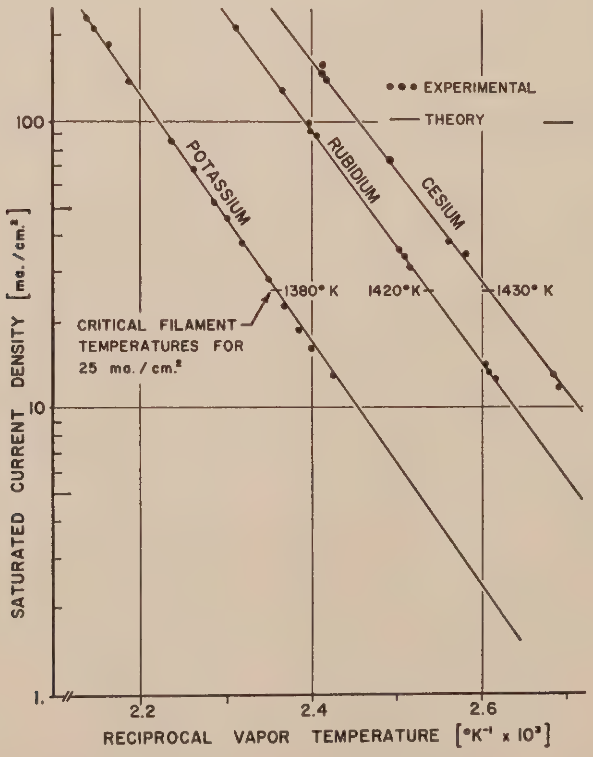


Fig. 5—Experimentally measured ion current densities from tungsten filaments [2].

low current densities function as expected for currents 1 to 200 times higher. Precise measurement of the critical temperature T_c at the higher ranges has not been possible, however, because of difficulties which plague experiments at high ion current densities. Temperature measurements on filaments as small as 0.002 inch are not satisfactory. Pyrometry is inaccurate because of filament vibration and measurements of temperature from the power input to the filament are uncertain because back bombardment by secondary electrons, which contributes significantly to the power, cannot be accurately estimated.

It is reasonably certain from the measurements that tungsten at 1450°K will support an ion current density of 25 ma/cm^2 with cesium and rubidium ions, giving an ionization energy consumption of 160 ev/ion, an acceptable value for practical purposes. The variation with temperature undoubtedly is close to that predicted from (9), so that values substantially below 100 ev/ion can doubtless be realized if the practical problems of handling higher current densities can be solved. While less than satisfactory from a scientific point of view, these statements are probably adequate for purposes of ionic propulsion in the present state of development. Practical thrust devices, as are discussed below, will use emitters much less simple than clean filaments in cylindrical geometry, and the value of T_c will be affected by changes in geometry, surface structure, and cleanliness. Moreover, problems more serious than exact knowledge of emitter temperature will dominate the field for a long time to come.

THE POROUS PLUG EMITTER

The line source in cylindrical geometry used in the experiments described above is not adapted for propulsion purposes. The production of an approximately unidirectional beam of ions with high mass flow rate raises serious problems in connection with supplying the neutral cesium to the hot surface. The electrical complications resulting from a high vapor pressure of cesium in the accelerating region are obvious. Also, leakage of neutral cesium from the exit apertures would cause appreciable wastage of mass. Such considerations have led many workers in the field to introduce the alkali vapor from the rear side of the emitter. Staggered ribbons, tungsten wire screens containing powders, and porous tungsten plugs have been tried [7].

The important questions are: 1) can an adequate mass flow be maintained at reasonable pressure; 2) can high enough current densities be drawn, and at temperatures which give ionization efficiencies comparable with those obtained using tungsten filaments; and 3) is the fraction of the alkali which escapes as neutral atoms sufficiently small?

Theoretical and experimental investigations of these questions will be described.

THEORY OF THE POROUS PLUG

We have cesium vapor proceeding from a supply at suitable pressure through a thickness of porous tungsten to an emitting surface, and wish to compute the fraction of atoms supplied which emerge as atoms, having failed to be ionized. We imagine the porous tungsten substructure to consist of long parallel tubes, of length L and radius a, with each tube servicing a plane emitting surface of radius $R=3a$. It will be convenient to study first the phenomena inside the tube, then the subsequent events on the emitting surface.

Inside the tube there are two phases of flow at the constant temperature of the tungsten, a volumetric phase of gaseous cesium atoms in the Knudsen regime and a surface phase diffusing along the wall under a concentration gradient. Wall coverage by the surface phase is never weak enough to permit appreciable internal ionization, which is therefore neglected. The two phases being coupled by the adsorption isotherm of Langmuir and Taylor [8], we can write Knudsen's equation for the flow rate I_v through the volumetric phase, the diffusion equation for the flow rate I_s through the surface phase, and form the quotient at $x=L$,

$$\left(\frac{I_v}{I_s}\right)_{x=L} = \frac{4}{3}\,\frac{a^2}{D_s\sigma_1}\exp\left\{62 - \frac{32380}{T}\right\}. \qquad (10)$$

This gives the proportion of emerging atoms which reach the end of the tube in the volumetric phase and are delivered un-ionized through the orifice. The balance continues to diffuse in the surface phase onto the disk-shaped emitting surface. In (10), σ_1 is the surface concentration of a complete monolayer of cesium on tungsten, $\sigma_1=3.6\times10^{14}$ atoms/cm^2. A word is required on the appropriate value of the temperature-dependent surface diffusion coefficient D_S, which is taken to be 2×10^{-4} cm^2/second at 1600°K. A sequence of two delay periods determines this coefficient: the residence time at a site while awaiting escape from confinement in the adsorption potential, and the travel time to the adjoining site after escape is accomplished. While the trap-escape process depends exponentially on the temperature, the transit process depends more weakly on the square root of the temperature. At low temperatures the exponential dependence is controlling, but at about 1000°K the delay in transit comes to predominate. Accordingly, at $T=1600$°K, D_S is almost insensitive to temperature, and has a value smaller by an order of magnitude than would be found by extrapolating exponentially from the low-temperature data.

Before leaving the flow phenomena inside the tube, we should estimate the cesium vapor pressure which can supply a suitably strong surface phase to the ionization surface, and from that result in a current density of, for example, $J=0.01$ ampere/cm^2. By choosing a pore radius $a=0.2$ μ, we can make the proportion of neutral emission in (10) negligibly small, and by choosing $L=0.015$ inch and $T=1600°\text{K}$ to conform with practical experimental conditions, we can compute $p=5.0$ mm Hg from the flow equation. This value of cesium vapor pressure is in equilibrium with the liquid at 350°C, and is manageable in practice. It confirms the validity of application of Knudsen's equation in the argument leading to (10).

Finally, we turn back to the portion of the flow in surface diffusion at the end of the tube, which migrates onto the disk-shaped emitting plane. We have the data of Taylor and Langmuir for rates of atom and ion emission and their dependence on the fraction of surface covered, which fraction decreases from a maximum at the tube outlet to a minimum at the outer periphery of the disk. Because of the space-charge limitation on ion emission, the ion current density is uniform. The atomic emission is not electrically limited and varies radially with the coverage over the disk in a distribution which may be integrated to give the total atom emission from the surface of the disk. At a current density $J=0.01$ ampere/cm², these computations lead to Table I.

TABLE I

Pore Radius (Microns)		Percentage of Neutral Atoms Emitted			
		At 1500°K		At 1600°K	
1.0	From Orifice	7		22	
	From Disk	4–7		9–15	
	Total		11–14		31–37
0.8	From Orifice	5		15	
	From Disk	3–4		7–9	
	Total		8–9		22–24
0.6	From Orifice	3		9	
	From Disk	2–3		5–6	
	Total		5–6		14–15
0.4	From Orifice	1		4	
	From Disk	1–2		3	
	Total		2–3		7
0.2	From Orifice	0.3		1	
	From Disk	1		1	
	Total		1		2

This compilation shows that the percentage of neutral atoms emitted falls rapidly as the pore radius is reduced from 1.0 μ, becoming acceptable at radii $a=0.2\ \mu$, and that it is advantageous to choose an operating temperature just above the critical temperature.

Experiment on the Porous Plug

Successful operation of porous tungsten emitters of cesium ions have been reported. Dulgeroff, Speiser, and Forrester [9] obtained a beam current of 0.0021 ampere, corresponding to a current density of about 0.012 ampere/cm² at the emitter, which was porous tungsten of 70 per cent theoretical density operated at 1575°K. Experiments by H. Shelton and J. M. Sellen have been directed toward measuring the fraction of neutral cesium atoms emitted from porous tungsten as the ion current density is increased. A heated tungsten probe is placed in the beam emitted from the plug and biased electrically so that it cannot receive the ionic component. Atoms incident on the probe are ionized, and the secondary ionic current from the probe is thus a measure of the atomic emission from the plug. At current densities of 0.0003 ampere/cm², the neutral emission from the plug was measured to be smaller than 5 per cent. Ionic current densities of 0.003 ampere/cm² have been drawn from a plug supplied at a cesium vapor pressure of 1 mm Hg, but, at this and higher densities, experimental circumstances prevented measurement of the associated atomic component. Special efforts were made to work at relatively low voltages of no more than a few hundred volts, but sputtering of cesium nevertheless occurred. Small interelectrode spacings were necessary to draw the higher current densities, and the full flow of ionic cesium collected and built up on the surfaces. Both the plug and the probe received substantial currents of atomic cesium sputtered from the electrodes.

It is believed that by choosing vapor temperature and plug temperature such as to keep the plug surface in the ion-emitting condition, much higher ion current densities can be drawn from porous tungsten plugs. Unambiguous proof of this and quantitative measurements of the atom-to-ion ratio will require great pains, particularly with respect to disposing of the mass transported by the ion beam and avoiding extraneous flows of cesium.

Charge Neutralization

The emission of many amperes of positive ion current from a space ship having a capacity of perhaps a millimicrofarad or less obviously imposes a severe requirement for maintaining the potential of the system in balance. A current of negative ions or electrons must be emitted in such a way as to meet simultaneously two separate conditions: 1) the net current from the space ship must be zero; 2) the space charge must be neutralized throughout the entire volume of the ion beam with sufficient accuracy to prevent serious loss of momentum or actual reversal of ion flow. The first condition presents no serious problem, since an electron beam can be ejected with the total desired current with small expenditure of energy and negligible transfer of momentum. But the neutralization of the ion beam throughout its volume appears to involve experimental and theoretical difficulties.

The following discussion first summarizes the behavior of unneutralized ion beams, and then presents theoretical results for some simple configurations of a neutralized beam for which analytical solutions can be found. While these idealized models do not adequately represent the real problem, they clarify some of the difficulties which must be overcome.

ONE-DIMENSIONAL THEORY OF UNNEUTRALIZED BEAMS [10]

Consider an emitter electrode at a positive potential V_0, an accelerating electrode at zero potential spaced at x_0, and a final electrode also at zero at a spacing x_1 from the accelerator. The current injected from the left is limited by Child's Law for the accelerating potential V_0 and the spacing x_0.

$$J = \frac{4}{9}\epsilon_0\sqrt{\frac{2q}{m}}\,\frac{V_0^{3/2}}{x_0^2}.$$

In the space between the two electrodes at zero potential, the injected current produces a distribution of positive potential which depends on the ratio of the spacings x_1/x_0 in the injection and acceleration regions. As x_1 is increased from zero, the distributions are at first symmetrical about a maximum at the mid-distance $x_1/2$. The space is weakly charged and all of the incident current is transmitted. We will call these Class I potentials; they are sketched in Fig. 6, curves *a*, *b*, and *c*. As x_1 continues to increase and approaches 2.82 x_0, $V_{1,\max}$ approaches $\frac{3}{4}V_0$, a limiting case, shown by curve *c*, which is unstable against upward fluctuations of the incident current or of the spacing x_1. Should either of these occur, the distribution jumps discontinously and irreversibly to curve *d*, which is a Class II potential, associated with space-charge-limited current. The incident current is partially reflected and contributes twice to the local space charge in the region to the left of the potential maximum, at which a virtual source has formed. Class II distributions are then found as x_1 increases toward infinity and these finally result in total reflection of the incident current. The ions will come to rest and reverse their motion at a distance 0.707 x_0 from the accelerating plane. Let x_1 now be decreased. The space-charge-limited situation and the Class II potential distribution persists, the fraction of transmitted current increases, and the virtual source shifts to the right. At $x_1 = 2x_0$, we have curve *e*, a limiting case for which the fraction of ions reflected is zero. This condition is unstable against downward fluctutations of the incident current or the spacing x_1. Should either of these occur, total transmission is established and the potential jumps discontinuously and irreversibly to curve *f*, a Class I distribution for which $x_1 = 2x_0$ and $V_{1,\max} = \frac{1}{4}V_0$.

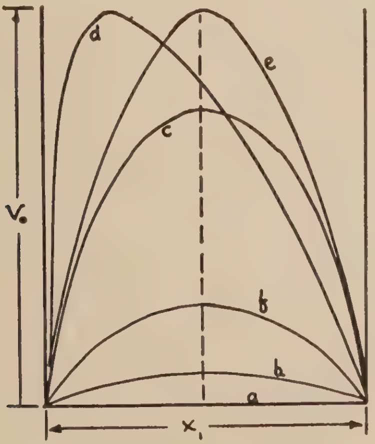


Fig. 6—Potential distributions produced by injection of monoenergetic ions into a region bounded by parallel planes at zero potential. The ions come to rest at potential V_0. The parameter which distinguishes the curves may be taken to be either the magnitude of the injected current density or the spacing x_0 to a third plane, to the left, which is held at potential V_0 and emits space-charge-limited ions.

Partial reflection cannot occur for $x_1 < 2x_0$, and total reflection must occur for $x_1 = \infty$, which is the case of an ion beam injected into infinite space. When $2x_0 < x_1 < 2.82x_0$, there is total transmission for Class I potentials and partial reflection for Class II potentials; but the two types of distribution cannot both exist together. Class I potentials are generated as x_1 increases through this interval; when the pattern of Class II is established, it persists while x_1 is returned through the interval in the decreasing sense. Practically, the largest value of x_1 which permits total transmission is just smaller than the instability at $x_1 = 2.82$ x_0, and must be reached in the increasing sense of x_1.

Neutralization must obviously be accomplished within a distance no greater then 2.82 x_0 from the injection plane. In a real configuration, as contrasted with the ideal plane diode, this requirement still applies if x_0 is taken as the "turn-around distance," the spacing of the equivalent diode which would produce the same current density at the same voltage as the ion beam under consideration. The actual beam might have been formed, for example, by the merging of a number of various beams, and a decelerating field might have been applied after the initial acceleration.

In sum, the foregoing analysis results in the following dilemma. In view of the dependence of thrust on aspect ratio, the requirement is for a broad beam with a large aspect ratio. But to broaden the beam indefinitely is to reduce it to one dimension, and a consequence of the one-dimensional analysis is the abrupt reflection of an unneutralized beam.

NARROW UNNEUTRALIZED BEAMS

The turn-around phenomenon described above in one-dimensional terms will occur only in a broad ion beam in which the diameter is considerably greater than the turn-around distance. If the aspect ratio $R \overset{\sim}{<} 1$, the beam will diverge but will not turn around [11]. The angle of divergence of a ray on the outside of the beam from the original direction of motion is given for small θ, by elementary considerations, as follows:

$$\theta \simeq 0.24R\left\{\ln\left[\frac{r}{r_0}\right]\right\}^{1/2},$$

where r is the radius of the expanded beam and r_0 is the initial beam radius. The contours of such beams are plotted in Fig. 7. The beams become essentially conical beyond a short distance ($\sim 10\ x_0$) from the orifice. Such beams will flow to very great distances from their source without turning back, even though no charge neutralization exists. Most beams of charged particles which are encountered in practical applications such as cathode ray tubes, mass spectrometers, and nuclear accelerators have aspect ratios much smaller than one. Beam power tubes such as klystrons and traveling-wave tubes require the highest perveance possible, and their beams are often prevented from expanding by longitudinal magnetic fields. Even in such cases, the maximum perveance achievable in a cylindrical beam corresponds to an aspect ratio of about 3 [11], the limit being established by the fact that ions on the axis of the beam are brought to rest by the space-charge repulsion. This represents the onset of the turn-around effect in the transition region of moderate values of R.

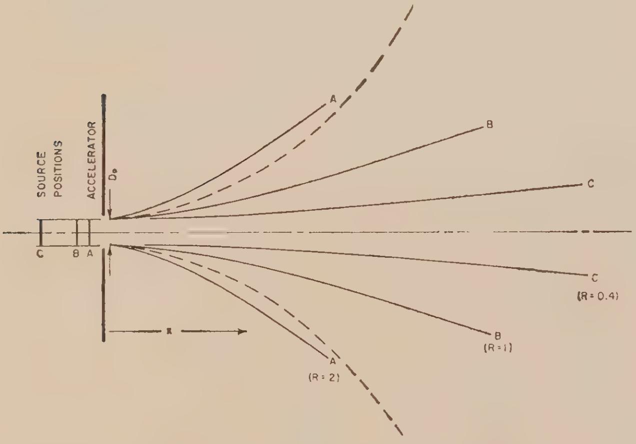


Fig. 7—Profiles of freely expanding beams for various aspect ratios (solid lines), and profile of an expanding slab beam (dashed line) whose thickness ($2y_0$) is equal to its acceleration distance (x_0).

SLAB BEAM

The behavior of a slab beam, narrow in the y direction but unlimited in z, can be calculated approximately from elementary considerations since the outward field E_y at all points along a given trajectory will be constant as long as the angle of divergence is small. If the width of the beam is $2y_0$ and the acceleration distance is x_0, the angle of divergence from the x axis of a ray at the outside of the beam will be

$$\theta \simeq 0.11\left(\frac{2y_0}{x_0}\right)\left(\frac{x}{x_0}\right).$$

The trajectory is a parabola. If the acceleration distance equals the beam width, the divergence will approach one radian at a distance of only about 10 acceleration distances, and the rate of increase will still be high. The behavior is completely different in magnitude from that of the pencil beam, and appears to offer little hope of relief from the essential problem of neutralizing high-perveance high-aspect ratio beams. With high-aspect ratios, it is essential that charge neutrality be achieved throughout the volume of the beam.

Recapitulating, we have discussed three possibilities for the unneutralized case: broad beams, pencil beams, and slab beams. The broad beams have large aspect ratios but turn around within a distance of the order of the equivalent diode spacing, as was shown from a one-dimensional argument. The pencil beams have small aspect ratios but a gentle conical divergence which enables them to flow to great distances without turning around. An intermediate class of slab beams offers moderate aspect ratios but has a bad divergence behavior.

The low aspect ratio beams can deliver appreciable thrust only when a large number are operated in parallel (*e.g.*, 2500 beams for each of which $R=1$ to give a thrust corresponding to $R=50$). But the suggested arrangement fails because of the interaction of the parallel beams. A group of parallel narrow beams are equivalent to a broad beam and will encounter the same turn-around difficulties.

THEORY OF NEUTRALIZED BEAMS IN ONE DIMENSION

We now take up neutralized beams, assuming that electrons are added to the ionic flow. The simplest case, in which the electrons have a unique initial velocity, is discussed first. The more realistic case of a thermal distribution of initial velocity is then examined. Finally a model in which electrons oscillate perpendicular to the direction of flow is discussed.

ELECTRONS EMITTED WITH UNIQUE VELOCITY—ONE-DIMENSIONAL FLOW [18]

If we define a potential V_e associated with the initial electron velocity $v_e(0)$, the conservation of energy yields

$$v_e(x) = \frac{2e}{m_e}\,[V_e + V(x)]^{1/2} = v_e(0)\,[1 + V(x)/V_e]^{1/2}.$$

We shall ignore variations in ion speed and take $v_p = (2eV_0/m_p)^{1/2}$. We also assume a current balance $J_p = \rho_p v_p = -J_e = -\rho_e v_e$, so that the vehicle will remain neutral. When these relations are substituted into Poisson's equation, we obtain

$$\frac{d^2V}{dx^2} = \frac{\rho_p}{\epsilon_0}\,[1/\gamma(x) - 1], \qquad (11)$$

where

$$\gamma(x) \equiv v_e(x)/v_p = \gamma_0[1 + V(x)/V_e]^{1/2}.$$

If $\gamma_0 = 1$, corresponding to equal initial ion and electron velocities, we have ideal charge neutralization since $V = 0$ is the solution satisfying $V(0) = V'(0) = 0$. If $\gamma_0 \neq 1$, there will be variations in the potential which can be determined by integrating (11). The qualitative nature of these variations can be easily deduced. If the exit speed of the electrons is less than that of the ions, then $\gamma_0 < 1$ and $V''(0) > 0$. Since we require $V'(0) = 0$, the potential curve rises as x increases until the electron speed equals that of the ions at position x_i where $\gamma(x_i) = 1$ and the curve has an inflection. Since $V''(x)$ is positive for $0 < x < x_i$, this region contains an excess of negative charge. Beyond x_i, γ is greater than one, so $V''(x)$ is negative, and an excess of positive charge is present. The curve reaches its maximum at a position x_m such that the positive charge accumulated between x_i and x_m is just sufficient to cancel the negative charge between 0 and x_i. The potential at larger values of x symmetrically retraces itself until the electron speed reaches its original value $v_e(0)$ at $x = 2x_m$. We are thus led to a periodic solution of which the amplitudes at the inflection point and maximum are easily obtained from (11). Setting $V''(x)$ equal to zero yields

$$V_{\text{inf}} = (1/\gamma_0^2 - 1)V_e = \alpha^2(1 - \gamma_0^2)V_0$$
$$\alpha^2 \equiv m_e/m_p.$$

To calculate $V_{\max}$ we obtain the first integral of (11),

$$\left(\frac{dV}{dx}\right)^2 = \frac{2\rho_p}{\epsilon_0}\left\{\frac{2V_e}{\gamma_0}[(1 + V/V_e)^{1/2} - 1] - V\right\}, \quad (12)$$

and set V' equal to zero with the result,

$$V_{\max} = \frac{4}{\gamma_0^2}(1 - \gamma_0)V_e = 4\alpha^2(1 - \gamma_0)V_0,$$

so that

$$V_{\max}/V_{\text{inf}} = 4/(1 + \gamma_0).$$

For $\gamma_0 = 0$, *i.e.*, $v_e = 0$, $V_{\max}/V_0$ takes on its largest value $4\alpha^2 = 4m_e/m_p$ and $V_{\max}/V_{\text{inf}}$ has the value 4. As γ_0 approaches 1, $V_{\max}$ approaches zero and $V_{\max}/V_{\text{inf}}$ the value 2, the curve becoming a sinusoid of low amplitude.

A similar discussion can be given if the electrons are initially moving faster than the ions, up to a certain point. In this case, $\gamma_0 > 1$ and the potential distribution curves downward as x increases. A potential minimum at x_m has a depth given by the above formula for $V_{\max}$, which continues to be a valid result for the extremum as γ_0 increases from unity to larger values.

$$V_{\min}/V_e = -\frac{4}{\gamma_0^2}(\gamma_0 - 1).$$

This ratio becomes -1 when $\gamma_0 = 2$. The electrons are then brought to rest at x_m. For larger values of γ_0, a fraction r of the incident electrons is reflected and we must modify (11) which becomes

$$\frac{d^2V}{dx^2} = \frac{\rho_p}{\epsilon_0}\left[\left(\frac{1 + r}{1 - r}\right)\Big/\gamma(x) - 1\right], \quad (11a)$$

differing from the case of no reflection only by the presence of the factor $(1 + r)/(1 - r)$. Our previous formulas involving γ_0 and V_e *uncombined* will still be valid for the case of reflection if γ_0 is replaced by $\gamma_0(1 - r)/(1 + r)$. We now have

$$\left(\frac{1 - r}{1 + r}\right)\gamma_0 = 2$$

or

$$r = (\gamma_0 - 2)/(\gamma_0 + 2) \qquad \gamma_0 \geq 2.$$

Returning to the first integral of (11) and integrating again, the exact solution has been obtained by Nazarian for the case of no reflection, *i.e.*, $\gamma_0 \leq 2$,

$$x = \frac{2V_e^{1/2}}{\gamma_0(2\rho_p/\epsilon_0)^{1/2}}\left\{\cos^{-1}\frac{1 - \gamma_0(1 + V/V_e)^{1/2}}{1 - \gamma_0} \mp \frac{\gamma_0\left[\left(\frac{dV}{dx}\right)^2\right]^{1/2}}{(2\rho_p/\epsilon_0)^{1/2}V_e^{1/2}}\right\}, \qquad 0 < x < x_m,$$

with $(dV/dx)^2$ as given in (12). The upper sign is taken for $\gamma_0 < 1$ and the lower one for $\gamma_0 > 1$. We find the location of the inflection,

$$x_i/x_m = \frac{1}{2}\left\{1 - \frac{2}{\pi}(1 - \gamma_0)\right\}$$

and the spatial period λ,

$$\lambda = 2x_m = \frac{4\pi\alpha V_0^{1/2}}{(2\rho_p/\epsilon_0)^{1/2}}, \quad (13)$$

having used the relation $V_e^{1/2}/\gamma_0 = \alpha V_0^{1/2}$. Thus λ is independent of the initial electron velocity in the range $0 \leq \gamma_0 \leq 2$ where there is no reflection and completely periodic solutions exist. Two forms of expression for λ are of particular interest. First, using Child's law, we find

$$\lambda = 2^{1/2}3\pi\alpha x_0 = 13.3\alpha x_0$$
$$= 0.027x_0, \text{ for cesium.}$$

Thus, because of the factor α, ($\alpha_{C_s} = 2.02 \times 10^{-3}$), the space wavelength is much smaller than x_0 the distance through which the ions are accelerated. The second form of λ is obtained by expressing (13) in terms of v_p instead of V_0. Thus,

$$\lambda^2 = 4\pi^2 v_p^2/\omega^2_{\text{plasma}}, \qquad \omega^2_{\text{plasma}} = e\rho_p/\epsilon_0 m_e,$$

so that in a frame of reference moving with the ions there occur periodic variations with time of the potential with exactly the plasma frequency.

The exact solution for the case of reflection, *i.e.*, $\gamma_0 \geq 2$ is

$$x = \frac{V_e^{1/2}}{(2\rho_p/\epsilon_0)^{1/2}} \left\{ \cos^{-1}\left[2(1 + V/V_e)^{1/2} - 1\right] + \frac{2\left[\left(\frac{dV}{dx}\right)^2\right]^{1/2}}{(2\rho_p/\epsilon_0)^{1/2} V_e^{1/2}} \right\}, \qquad 0 \leq x < x_m.$$

Comparing with the fixed value of x_m for the case of no reflection, we find

$$\frac{(x_m)_{\text{refl}}}{(x_m)_{\text{no refl}}} = \frac{1}{2}\gamma_0 \qquad \gamma_0 \geq 2.$$

At $(x_m)_{\text{refl}}$ the periodic solution corresponding to $\gamma_0 = 0$ joins on smoothly to the solution just found for the region $0 \leq x \leq x_m$, and starts off with the value $-V_e$. Fig. 8 shows a family of potential distributions generated as the parameter γ_0 varies from 0 to 2 which is the domain of no reflection, and beyond 2 where partial reflection must occur.

ELECTRONS EMITTED WITH A MAXWELLIAN DISTRIBUTION OF VELOCITIES [19]

With an arbitrary distribution $f(x, v)$ of electron speeds we have, for the forward current,

$$J_e = -e\int_0^\infty f(x, v)v\,dv = -e\mathbf{v}(x)\int_0^\infty f(x, v)\,dv = \mathbf{v}(x)\rho_e(x)$$

so that $\mathbf{v}(x)$ the mean speed in the distribution replaces the speed $v_e(x)$ of the unique velocity case. Thus, the condition for ideal neutralization is

$$v_p = \mathbf{v}(0).$$

For a Maxwellian distribution at the origin,

$$f(0, v_0) = A\exp(-m_e v_0^2/2kT) \qquad V_0 \geq 0,$$

the condition becomes

$$v_p = (2kT/\pi m_e)^{1/2}$$

If $\mathbf{v}(0) < v_p$, the argument for determining the steady-state potential proceeds exactly as for the unique velocity case except that we now speak of the *mean* electron speed. The velocity distribution is alternately shifted from lower to higher values of v, $\mathbf{v}(x)$ oscillating in value around v_p. The form of the distribution at various locations can be sketched as shown in Fig. 9(a). Periodic potential solutions have been obtained by an approximation method for this case of $\mathbf{v}(0) < v_p$ but will not be presented here.

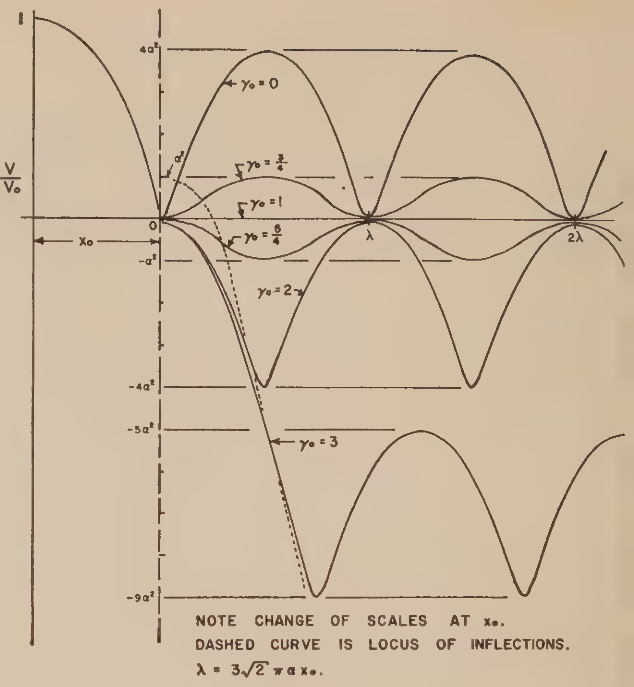
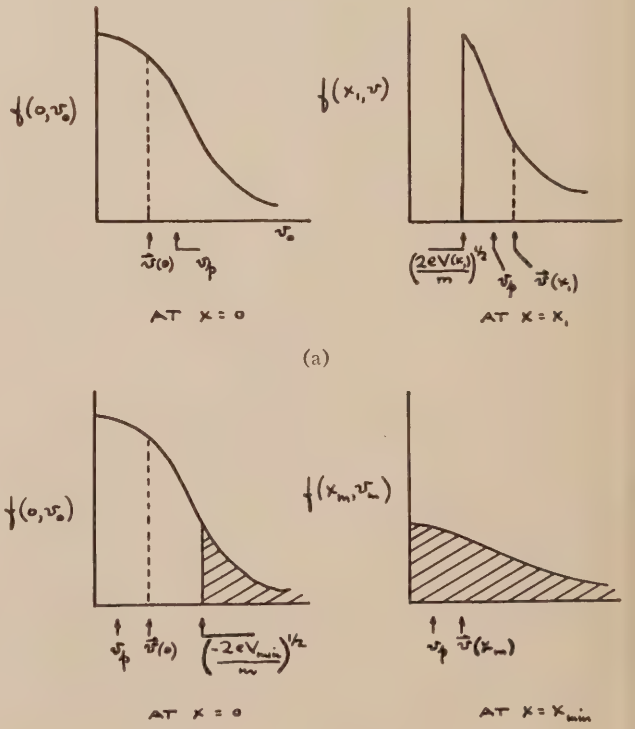


Fig. 8—One-dimensional potential distribution in an ion beam into which monoenergetic electrons have beeen injected parallel to the direction of ion flow. γ_0 is the ratio of initial electron to ionic velocity. Reflection of electrons occurs if $\gamma_0 > 2$. The wavelength $\lambda \ll x_0$.



(a)

(b)

Fig. 9—(a) Distribution function at different locations for the case $\mathbf{v}(0) < v_p$. (b) Distribution function at exit and potential minimum for the case $\mathbf{v}(0) > v_p$. The shaded portion is contributed by those electrons which eventually reach $x_{\min}$.

It might be thought at first that the situation for $v(0) > v_p$ is also similar to that of the corresponding unique velocity case, with the improvement that reflection can be interpreted properly as a separation of low-energy electrons from high-energy ones, rather than improperly by artificially attributing different behavior to electrons having identical energies. Arguing by analogy with the unique velocity case, we would expect the potential to fall as x increases and the electrons to be slowed down. However, this would result in continuous reflection of those electrons with sufficiently small initial velocities, and it is therefore the transmitted fraction of electron current which we must equate to the ion current leading to

$$\rho_e(x_m) = -J_p/v(x_m)$$

and we need $v(x_m) < v_p$ to give the potential a positive curvature. The question is whether v for the electron distribution at the minimum can be less than v_p as a consequence of the potential energy barrier, $-eV_m$ [Fig. 9(b)]. The answer to this question is in the negative since from Liouville's theorem we find

$$f(x_m, v_m) = A \exp(-m_e v_m^2/2kT) \exp(eV_m/kT) \quad v_m \geq 0$$

so that, in fact,

$$v(x_m) = v(0).$$

It is as though the potential barrier in the metal, corresponding to the electron work function, were increased and extended further out into space. The electrons would be emitted from this new "metal" in a Maxwellian distribution having precisely the same mean speed as the distribution emitted from the actual metal. The "work function" has increased by the amount $-eV_m$ with a corresponding decrease in the emitted electron current as expressed by the factor $\exp(eV_m/kT)$.

So if $v > v_p$ originally, then no matter how far the potential were to fall, v would remain unchanged. The only change in v/v_p would result from the accelerating effect of the field on the ions, which effect would be negligible in practice since $-eV_m$ must be of order kT or smaller to enable an appreciable fraction of the electron current to pass the barrier. We arrive at the important conclusion that if the electrons are emitted with a Maxwellian distribution of velocities, our one-dimensional model leads to stationary potentials only if at the exit plane the mean electron speed is less than the ion speed.

The condition will not be satisfied for most ion propulsion systems using alkali ions. At 1500°K, the mean electron speed will be 120 km/second, corresponding to a specific impulse of 12,000 seconds. A cesium ion voltage of 10 kilovolts would be required to match this electron velocity. These velocities are higher than the optimum values for many applications envisaged for ionic propulsion.

It is clear from the above discussion and from other obvious facts that the one-dimensional solutions of the neutralization problem have little if any relation to the practical case. The electrons cannot be introduced from an ideal plane source nor can their velocities be sufficiently small to satisfy the mathematical conditions postulated above. If the beam is not extremely well neutralized, positive potentials will develop which will accelerate electrons to speeds many times that of the ions. Multiple reflections of electrons will be essential to maintain current and charge equality.

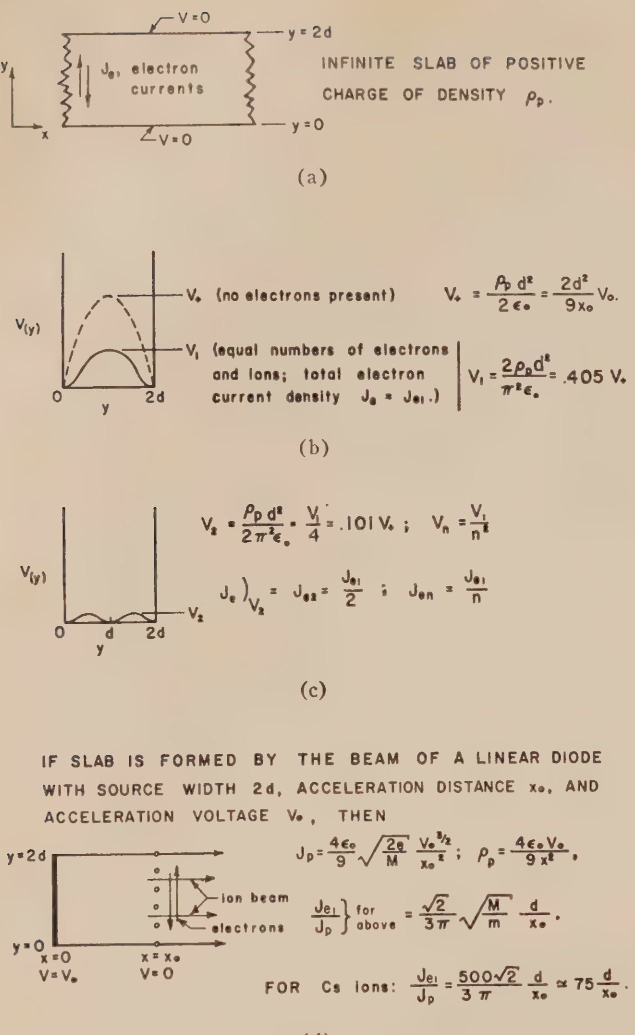
A neutralization model which provides for multiple reflections of the electrons is that of transverse injection. Electrons are injected into the ion stream with initial directions which are perpendicular to the motion of the ions and oscillate back and forth across the ion beam under the influence of space charge fields. In order to provide equal ion and electron currents in the exhaust, the electrons can drift along the propulsive axis at a mean rate equal to the ion velocity. The behavior of electrons and ions in such a neutralization scheme leads to the simplified model of bipolar flow which is discussed in the following section.

NEUTRALIZATION WITH TRANSVERSE FLOW OF ELECTRONS

A second example of bipolar space and charge dynamics for which solutions may be easily obtained is the one-dimensional flow of electrons across an infinite slab of positive charge, as illustrated in Fig. 10(a). Electrons flow back and forth along the y direction from $y=0$ to $y=2d$, and the potential $V=0$ on the planes at these extreme positions. The positive charge is assumed to be fixed in space and of uniform density ρ_p in the region between $y=0$ and $y=2d$, and electrons are emitted with zero energy from these two planes. Poisson's equation, combined with others for continuity and conservation of energy, becomes

$$\frac{d^2V}{dy^2} = \frac{-\rho_+}{\epsilon_0} + \frac{J_e}{\epsilon_0\sqrt{\dfrac{2eV}{m}}},$$

where J_e is the total electron current density flowing in both directions; *i.e.*, the total current flux. If the total negative charge flowing back and forth is equal to the total positive charge in the slab, dV/dy vanishes at the boundaries, from Gauss' theorem. Solutions of the bipolar flow equation under these conditions are identical with those in (11) to (13) if γ is taken as the ratio of J_e (along y) to J_p at the point of maximum electron velocity at the bottom of the potential trough ($y=d$). The



V=0
y=2d
J_e, electron currents
INFINITE SLAB OF POSITIVE CHARGE OF DENSITY ρ_p.
y=0
V=0
y
x
(a)
V(y)
V* (no electrons present)
$V_* = \frac{\rho_p d^2}{2\epsilon_0} = \frac{2d^2}{9x_0} V_0$.
V₁ (equal numbers of electrons and ions; total electron current density $J_e = J_{e1}$.)
$V_1 = \frac{2\rho_p d^2}{\pi^2 \epsilon_0} = .405\, V_*$
0 y 2d
(b)
$V_2 = \frac{\rho_p d^2}{2\pi^2 \epsilon_0} = \frac{V_1}{4} = .101\, V_*$; $V_n = \frac{V_1}{n^2}$
$J_e\big)_{V_2} = J_{e2} = \frac{J_{e1}}{2}$; $J_{en} = \frac{J_{e1}}{n}$
V(y)
V₂
0 d 2d
y
(c)
IF SLAB IS FORMED BY THE BEAM OF A LINEAR DIODE WITH SOURCE WIDTH 2d, ACCELERATION DISTANCE x₀, AND ACCELERATION VOLTAGE V₀, THEN
$J_p = \frac{4\epsilon_0}{9} \sqrt{\frac{2e}{M}} \frac{V_0^{3/2}}{x_0^2}$; $\rho_p = \frac{4\epsilon_0 V_0}{9 x_0^2}$,
y=2d
ion beam
electrons
$\left.\frac{J_{e1}}{J_p}\right\}$ for above $= \frac{\sqrt{2}}{3\pi} \sqrt{\frac{M}{m}} \frac{d}{x_0}$.
y=0
x=0 V=V₀
x=x₀ V=0
FOR Cs ions: $\frac{J_{e1}}{J_p} = \frac{500\sqrt{2}}{3\pi} \frac{d}{x_0} \cong 75 \frac{d}{x_0}$.
(d)

Fig. 10—Summary of the properties of a slab beam of ions across which space-charge-limited electrons, oscillate transversely, assuming that no potential variations occur along the axis of the beam. To prevent some ions from coming to rest, the electron emitting planes must be less than about $3x_0$ apart, and J_e, the total transverse electron current density must be much larger than the ion current density, J_p.

ratio of electron to ion current densities is given by

$$J_e/J_p = \frac{\gamma_0}{2} = \frac{\sqrt{2}}{3\pi}\sqrt{\frac{M}{m}}\,\frac{d}{x_0} \qquad (14)$$

and the depth of the potential trough is

$$V_1/V_0 = 0.090\,\frac{d^2}{x_0^2}\,. \qquad (15)$$

The properties of solutions of this type have been discussed by Naiditch, *et al.* [12].

A family of solutions results from the boundary conditions prescribed, two of which are illustrated in Fig. 10(b) and 10(c). The first consists of a single excursion in V, having maximum value V_1, as one moves from $y=0$ to $y=2d$. The second solution has only half the wavelength (*i.e.*, d), and an excursion in V which is $\frac{1}{4}$ of that for the first solution. The succeeding solutions have wavelengths of $2d/n$, and excursions in V of V_1/n^2. The parameter which is varied as one moves throughout this family of solutions is J_e, the electron current density. If the electron current density for which the first solution results is denoted as J_{e1}, the current densities for succeeding solutions with n wavelengths across the slab are given by J_{e1}/n. The required magnitude of J_{e1} relative to J_p, the ion current density, is indicated in Fig. 10(d).

The relationships presented in Fig. 10 permit preliminary estimates of the performance of a hypothetical transverse neutralizing system to be readily stated. Imagine a square uniform emitting area of side L, transmitting space-charge-limited ions from a source at acceleration distance $x_0 \ll L$. Let the electron emitters be ribbons mounted edgewise to the beam between which electrons travel transversely. Let the spacing between ribbons be $2d$, and the width of the ribbons be d. The total electron emitting area counting both sides of the ribbon is then L^2, for any value of d. The total electron current, for cesium ions, will be $75\ d/x_0$ times the ion current. By reducing d, the total electron current and the potential fluctuations in the neutralized beam will be reduced at the cost of added complexity of the ribbon structure. When $d=3.3x_0$, the analysis in Fig. 10 shows that $V_1=V_0$ and that the ions in the center of the beam would come to rest. Actually the assumption of uniform ion space charge makes the analysis not valid in this range, and the actual upper limit on d as set by onset of ion turn-around will be smaller than $3.3x_0$.

The treatment to this point has assumed that $V=V(y)$, and that no fields exist in directions other than the y direction. The placement of conducting planes at $y=0$ and $y=2d$ would provide that the conditions $\partial V/\partial x=0$ are, at least, met at the boundaries of the ion stream. The slab of charge, however, is neither infinite nor fixed, but is, in reality, a finite ion beam emerging from the acceleration region. With such an ion beam, axial electric fields exist which may be comparable with or larger than the fields in the y direction, and electrons, accelerated into the positive charge by these space-charge fields, may possess velocities along the axial direction of the same magnitude as their velocities transverse to the ion flow. The velocities of such electrons along the axial direction would be many times greater than ion velocities and the condition of electron drift velocities equal to the ion velocity would not be realized.

Thus, while the special situation of bipolar flow with spatial dependence in only the transverse direction provides revealing information about the qualitative nature of the neutralization problem, the existence of variations in V, ρ_+, and J_e in the x direction demands that the study of the motion encompass these complicating features if an adequate solution is to be found.

HEAVY PARTICLE PROPULSION

The problem of charge neutralization could be greatly simplified if particles of higher mass-to-charge ratio could be used. The difficulties of small electrode spacings would also be avoided, but a large number of new problems would also be introduced [20].

After converting the exit velocity to a specific impulse, we can combine (2) and (7) to give

$$F = \frac{\pi}{18} \epsilon_0 g^4 \left(\frac{m}{q}\right)^2 (I_{sp})^4 R^2.$$

For fixed aspect ratio and specific impulse, the thrust available from a beam is thus proportional to $(m/q)^2$. The advantage of high m/q lies in the opportunity to make R small. As pointed out in Fig. 7 and the associated discussion, a beam for which $R \sim 1$ will penetrate to a great distance into space, thus avoiding problems of turn-around of ions. If an equal electron current is projected in the same general direction, neutralization would presumably occur in a sufficiently remote, diffuse, and large region to make detailed mechanisms and space-charge disturbances irrelevant.

Fig. 2 shows the numerical values which apply if current is space-charge limited.

A method of charging and accelerating ion particles has been described by Shelton, Hendricks, and Wuerker [13]. The particles are charged by projecting them onto the surface of a conducting point maintained at a high potential. Theoretically, the maximum charge which can be placed on the particles is limited by the onset of field emission. If the limiting field strength is E_1, the minimum mass-to-charge ratio for a spherical particle of density ξ is

$$\frac{m}{q} = \frac{r\xi}{3\epsilon_0 E_1}.$$

The experimental value of E_1 is reported by Müller in connection with his work on the field emission microscope [14] at $E_1 \sim 10^{10}$ volts per meter for positively charged surfaces. The highest values of surface fields actually achieved and reported by Shelton, Hendricks, and Wuerker are about 2.5×10^9 volts per meter. This would correspond to a mass-to-charge ratio of 0.01 kilogram per coulomb on a 0.1-micron radius sphere, and to a velocity of 14 km/second ($I_{sp} = 1400$) with an accelerating potential of 10^6 volts. For higher I_{sp}, smaller particles would have to be used. In these experiments, the particle numbers were small, and present techniques are inadequate to produce a particle flux of sufficient magnitude to be useful.

A method which has been proposed for obtaining many particles with low m/q ratio is that of charging liquid droplets. Zelany [15] found that when the surfaces of liquids are subjected to high fields, they become unstable and eject sprays of small, charged droplets. At any small surface irregularity, the field strength is increased (fixed potential) and hence the tension of the surface due to the electric field is increased at the irregularity. The increase in tension further distorts the surface and the process continues until a point of liquid emerges from the surface. A fine spray of charged droplets issues from the liquid point. Schultz [16], Hendricks [17], and others have investigated charged liquid droplets as the possible working substance in an electrostatic, heavy-particle, thrust-producing device. Hendricks has measured diameters and charges of a sample of about 1000 droplets, finding many having a useful q/m, but a wide spread of lower values also.

In order to prevent the voltages from reaching unreasonably high values (*i.e.*, many megavolts) particles considerably smaller than one micron must be used.

A large extension of present techniques in electrical acceleration and ion optics will also be involved. While a value of aspect ratio R close to unity provides an attractively narrow beam compared to those required with elemental ions, it is very large relative to present practices in high voltage dc accelerators. A beam current of one milliampere at one mev has an aspect ratio of about 1/1000 for electrons, and 1/140 for protons.

CONCLUSION

Although electrical forces are sufficiently familiar, they have not yet been used to propel a space vehicle. The problems of efficiently producing and initially accelerating an ionic flow satisfactorily uncontaminated with neutral atoms appear to be essentially solved. Ion optics and sputtering, which have not been discussed in this paper, are problems which have not yet received adequate attention. Although their solution is vital to the achievement of adequate service life, they may be regarded presently as subordinate to the central problem of actually demonstrating significant thrust. The crucial importance of such a demonstration is pointed up by the following considerations: 1) all experiments thus far reported have been limited to low-aspect ratio, the perveances being two to three orders of magnitude smaller than those required for a practical device; 2) the experiments conducted at low perveance cannot be scaled up or operated in parallel because the high perveance beam raises problems different in kind from those encountered at low perveance; and 3) the problem of neutralizing a high perveance beam remains to be solved theoretically and experimentally.

NOMENCLATURE AND NOTATION

Italic Symbols

a = radius of a representative pore in a porous tungsten emitter;
A = area;
D = diameter, or representative length associated with the emitting area of an electrode;
D_s = the coefficient of surface diffusion for cesium on tungsten;
E, E_x, E_y, E_z = the electric field and its rectangular components;
F = thrust;
I = electric current;
g = acceleration of gravity;
I_v = volumetric portion of a gaseous flow rate;
I_s = adsorbed surface portion of a flow rate;
J = electric current density, amperes per unit area;
k = Boltzmann's constant;
L = length of a representative flow path through porous tungsten;
$\dot{M}$ = mass flow rate per unit area from an electrostatic thrust engine;
m, m_p, m_e = mass of a particle, and of an ion and electron, respectively;
n = numerical density of particles;
P = perveance;
q = charge per particle;
R = aspect ratio of a beam of particles, or transverse dimension divided by the acceleration distance;
r, r_0 = radius of a gently expanding pencil beam and its initial value; radius of a small sphere;
T = temperature, degrees Kelvin;
T_c = that temperature of an emitter at which the ionic emission predominates over the atomic emission;
v, v_p, v_e = velocity of a particle and of an ion and electron, respectively;
V = electric potential;
V_0 = the value of the potential drop across a diode accelerator;
V_e = the potential which is associated with an electronic velocity;
x, y, and z = Cartesian coordinates—x is taken as the direction of space dependence in all one-dimensional treatments;
x_0 = the spacing of a diode accelerator;
x_1 = a spacing downstream of a diode accelerator.

Greek Symbols

α^2 = ratio of electronic to ionic mass;
γ, γ_0 = ratio of electronic to ionic velocity, and its initial value, in the one-dimensional problem;
ϵ_0 = the permittivity of empty space;
λ = a spatial period or wavelength;
ρ, ρ_p, ρ_e = charge density, and density of ionic and electronic charge, respectively;
σ_1 = surface concentration of a monolayer of cesium on tungsten;
ξ = density of a small particle;
ω_{plasma} = the angular frequency of oscillations in a plasma.

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Photon Propelled Space Vehicles*

D. C. HOCK†, F. N. McMILLAN†, AND A. R. TANGUAY†, SENIOR MEMBER, IRE

Summary—**The interplanetary trajectories of vehicles propelled by solar radiation pressure are analyzed, and are shown to be logarithmic spirals if thrust direction is constant with respect to the vehicle-sun line. The required thrust may be obtained with a solar sail.**

Sail size as a function of trip time to Mars is determined for solar thrust, oriented tangent to the trajectory.

Solar propulsion is compared with chemical and electrical propulsion. It is shown that a solar-sail-powered space vehicle on a journey from earth to Mars operates with a payload and flight time penalty when compared with a ballistic vehicle. However, the work capacity per unit weight of a solar sail is calculated to be superior to an electrical engine, which in turn is vastly superior to a chemical engine when the work is compared on the basis of equal flight times.

INTRODUCTION

FORBES[1] showed that a logarithmic spiral is the space trajectory which results when thrust is applied tangent to the flight path, and when the magnitude of thrust is proportional to the inverse square of distance to the sun. Since the required thrust is small, the use of a solar sail is suggested. In this paper it is shown that the application of an inverse square thrust tangent to the flight path results in a special case of a more general class of logarithmic spiral trajectories.

Although some questions have been raised concerning the practical feasibility of solar sail vehicles for space travel, comparison with other continuous-thrust engines indicates that solar sailing must be given serious consideration in the light of present-day technology.

NOTATION

r = distance from sun to vehicle,
θ = longitude angle measured from the point where logarithmic spiral trajectory intersects the orbit of earth,
p = solar sail tilt parameter $= (\tan \phi)^{-1} = F_r/F_\theta$,
A = area of sail,
F_r = force per unit mass along radius vector,
F_θ = force per unit mass perpendicular to radius vector,
β = angle between tangent to spiral and radius vector,
q = constant in logarithmic spiral curve, $r = e^{q\theta}$, $= (\tan \beta)^{-1}$,
μ = gravitational constant of the sun,
S = solar constant,
m = total mass of vehicle,
t = time,
v = velocity.

Dots denote a differentiation with respect to time; subscripts o denote initial conditions; and subscripts f denote final conditions.

EQUATIONS OF MOTION

If the applied thrust is zero, and forces are resolved along a radius vector to the sun and perpendicular to the radius vector (circumferential), then the equations of motion in a central force field are:

$$\ddot{r} - r\dot{\theta}^2 + \frac{\mu}{r^2} = 0, \tag{1}$$

$$\frac{1}{r}\frac{d}{dt}(r^2\dot{\theta}) = 0. \tag{2}$$

When forces per unit mass F_r and F_θ are applied in the radial and circumferential directions respectively, then (1) and (2) become:

$$\ddot{r} - r\dot{\theta}^2 + \frac{\mu}{r^2} = F_r, \tag{3}$$

$$\frac{1}{r}\frac{d}{dt}(r^2\dot{\theta}) = F_\theta. \tag{4}$$

Assume that the trajectory is a logarithmic spiral of the form

$$r = e^{q\theta}, \tag{5}$$

where $1/q = \tan \beta =$ a constant. The geometry of the situation is described in Fig. 1.

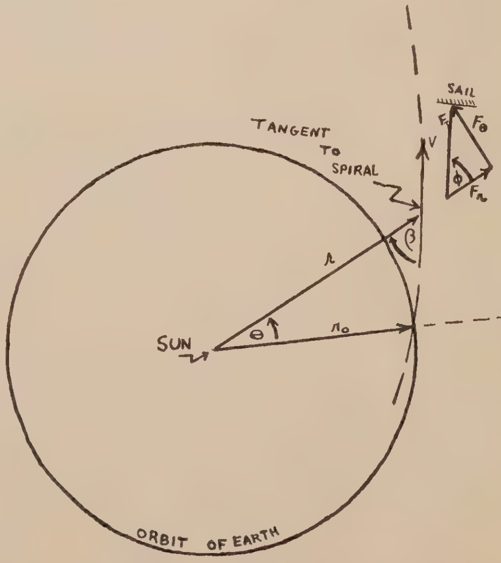

Fig. 1—Geometry of logarithmic spiral trajectory.

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* Original manuscript received by the IRE, December 11, 1959.

† Res. Div., Radiation Inc., Orlando, Fla.

[1] G. F. Forbes, "The trajectory of a powered rocket in space," *J. Brit. Interplanetary Soc.*, vol. 9, pp. 75–79; March, 1950.

Eqs. (3) and (4) may then be solved for r and θ as functions of time. Time differentiation of (5) provides:

$$\dot{r} = qr\dot{\theta}, \tag{6}$$

$$\ddot{r} = q\dot{r}\dot{\theta} + qr\ddot{\theta} = q(\dot{r}\dot{\theta} + r\ddot{\theta}). \tag{7}$$

After performance of the indicated differentiation in (4), F_θ is shown to be

$$F_\theta = 2\dot{r}\dot{\theta} + r\ddot{\theta} = (\dot{r}\dot{\theta} + r\ddot{\theta}) + \dot{r}\dot{\theta}. \tag{8}$$

Substitution of (8) into (7) yields

$$\ddot{r} = q(F_\theta - \dot{r}\dot{\theta}). \tag{9}$$

Now, $\ddot{r}$ in (9) may be set equal to the $\ddot{r}$ in (3) so that:

$$F_r + r\dot{\theta}^2 - \frac{\mu}{r^2} = qF_\theta - q\dot{r}\dot{\theta}. \tag{10}$$

Now let the sail apply forces per unit mass F_r and F_θ in a constant ratio p, such that

$$\frac{F_\theta}{F_r} = \frac{1}{p} = \tan\phi, \tag{11}$$

where ϕ is the angle between the sail normal and the radius vector to the sun. ϕ is also the angle of incidence of sunlight on the sail, as shown in Fig. 1. By combining (6), (10), and (11), we obtain:

$$F_\theta(p - q) + r\dot{\theta}^2(1 + q^2) = \frac{\mu}{r^2}\cdot \tag{12}$$

Since solar pressure falls off as $1/r^2$, let $F_\theta = K_1/r^2$. Then (12) may be solved for $\dot{\theta}^2$, which yields

$$\dot{\theta}^2 = \frac{\mu + K_1(q-p)}{r^3(1+q^2).} = \frac{\mu + K_1(q-p)}{1+q^2}e^{-3q\theta}; \tag{13}$$

and, since

$$2\ddot{\theta} = \left[\frac{\mu + K_1(q-p)}{1+q^2}\right](-3q)e^{-3q\theta}, \tag{14}$$

then

$$\ddot{\theta} = -3/2q\dot{\theta}^2. \tag{15}$$

From (8):

$$F_\theta = 2qr\dot{\theta}^2 - 3/2rq\dot{\theta}^2 = \frac{qr\dot{\theta}^2}{2} = \frac{K_1}{r^2} \tag{16}$$

or

$$\frac{K_1}{r^2} = \frac{q}{2r^2}\left[\frac{\mu + K_1(q-p)}{1+q^2}\right], \tag{17}$$

and

$$K_1 = \frac{q\mu}{q^2 + qp + 2}\cdot \tag{18}$$

Thus,

$$F_\theta = \frac{q\mu}{r^2(q^2 + qp + 2)}, \tag{19}$$

and

$$F_r = \frac{pq\mu}{r^2(q^2 + qp + 2)}\cdot \tag{20}$$

Eq. (13) may be integrated to yield

$$e^{3/2q\theta} = 3/2q\sqrt{\frac{\mu + K_1(q-p)}{(1+q)^2}}\,t + e^{3/2q\theta_o}, \tag{21}$$

where $\theta = \theta_o$ when $t = 0$.

Thus (5) and (21) yield

$$r^{3/2} = \frac{3q}{2}\sqrt{\frac{\mu + K_1(q-p)}{1+q^2}}\,t + r_o^{3/2}. \tag{22}$$

TANGENTIAL THRUST

In the case where the force is applied tangent to the rocket path, then q equals p, $\beta = \phi$, and (19), (20), and (21), (22) respectively reduce to:

$$F_r = \frac{\mu p^2}{2r^2(p^2+1)}, \tag{23}$$

$$F_\theta = \frac{\mu p}{2r^2(p^2+1)}, \tag{24}$$

$$e^{3/2p\theta} = 3/2p\sqrt{\frac{\mu}{p^2+1}}\,t + e^{3/2p\theta}o, \tag{25}$$

$$r^{3/2} = 3/2p\sqrt{\frac{\mu}{p^2+1}}\,t + r_o^{3/2}. \tag{26}$$

SAIL AREA AS A FUNCTION OF TRIP TIME

The case of thrusting tangent to the trajectory results in larger sail areas than necessary, but serves as a simple illustration of the method of determining the sail size. Later, we will show sail areas obtained for optimized tilt angles.

Fig. 2 represents the geometrical and force relationships of the sail with respect to the incident and reflected radiation from the sun.

A sail of area A is oriented so that light incident upon it makes an angle ϕ with the normal to the sail. The projected area of the sail, perpendicular to the incident radiation, is $A\cos\phi$. If S is the solar constant at Earth, and $S\cos\phi$ the radiation pressure normal to the sail, then the component of force in the radial direction must equal mF_r. Thus,

$$SA\cos^3\phi = \frac{\mu}{2r^2}\,\frac{p^2\ m}{p^2+1}, \tag{27}$$

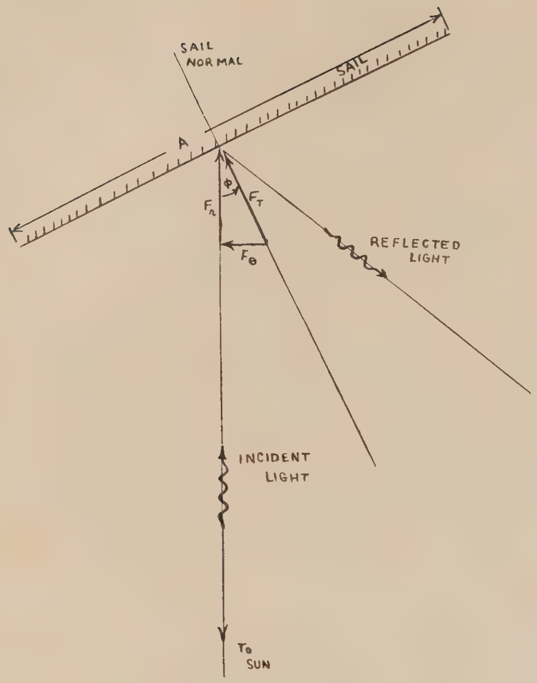

Fig. 2—Geometrical relationship of the sail to the incident and reflected radiation from the sun and resultant forces.

where r is now understood to be one astronomical unit and m is the total vehicle mass. Since $\tan\phi = 1/p$, then

$$\cos\phi = \frac{p}{\sqrt{p^2+1}}, \tag{28}$$

and

$$SA = \frac{\mu m}{2r^2}\left[\frac{(p^2+1)^{1/2}}{p}\right]. \tag{29}$$

The area of the sail required per unit total vehicle mass is

$$\frac{A}{m} = \frac{1}{S}\,\frac{\mu}{2r^2}\,\frac{(p^2+1)^{1/2}}{p}. \tag{30}$$

Since[2] S is 0.89×10^{-4} dynes/cm² at r equal to 1.50×10^{13} cm, and μ is 1.32×10^{26} cm³/sec², then

$$\frac{A}{m} = 0.33 \times 10^4\,\frac{(p^2+1)^{1/2}}{p}\ \text{cm}^2/\text{gm}. \tag{31}$$

In order to evaluate it as a function of trip time to Mars, rewrite (26) as

$$\frac{r_f^{3/2} - r_o^{3/2}}{3/2\mu^{1/2}} = \left[\frac{p}{(p+1)^{1/2}}\right]t. \tag{32}$$

If the journey starts at Earth and ends at Mars, then

$$r_f = 1.524\ \text{AU}, \qquad r_0 = 1.000\ \text{AU}$$

and

$$\mu = 0.0002959\ (\text{AU})^3/\text{day}^2,$$

and

$$\frac{(p^2+1)^{1/2}}{p} = \frac{t}{34.16\ \text{days}}. \tag{33}$$

The resultant area of sail required per unit mass is given in Table I in cm²/gram and in ft²/lb for various transfer times to Mars. The transfer angle, θ, measured from the start of the logarithmic spiral trajectory, is also listed.

TABLE I

Area of Sail per Unit Mass (cm²/gm) or per Unit Weight (ft²/lb) and Transfer Angle as Functions of Transfer Time for Thrust Applied Tangent to Trajectory

Transfer time (days)	$\frac{p}{(p^2+1)^{1/2}}$	Sail area per unit mass or earth weight		Transfer angle, θ in radians
		$\frac{\text{cm}^2}{\text{gm}}$	ft²/lb	
80	0.427	77×10^2	37×10^2	0.9
100	0.342	97×10^2	47×10^2	1.2
150	0.228	140×10^2	70×10^2	1.8
200	0.171	190×10^2	94×10^2	2.4
250	0.137	240×10^2	110×10^2	3.1
300	0.114	300×10^2	150×10^2	3.7

The increase in sail area as journey time increases is explained in the term $\cos^3\phi$ in (27). Although the required solar force decreases in magnitude as p decreases (*i.e.*, as the spiral angle ϕ increases), the corresponding reduction in effective sail area causes a net increase in required sail size. However, the energy necessary to inject the space vehicle into the spiral orbit is greater for shorter transfer times. Hence, optimization on a complete vehicle systems basis is indicated.

Vehicle Acceleration

The total acceleration per unit mass (F_T) provided by the sail for the cases of tangential thrust may be determined from:

$$F_T^2 = F_r^2 + F_\theta^2 \tag{34}$$

and

$$F_T = \frac{\mu}{2r^2}\,\frac{p}{(p^2+1)^{1/2}} = 296\,\frac{\text{cm}}{\text{sec}^2}\,\frac{p}{\sqrt{p^2+1}}. \tag{35}$$

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[2] C. D. Hodgman, Ed., "Handbook of Chemistry and Physics," U. S. Chemical Rubber Publishing Co., p. 2626; 1947.

This acceleration decreases as the vehicle travels farther from the sun. Table II lists the g's acceleration experienced by the sail in the vicinity of Earth and in the vicinity of Mars, as a function of transfer time.

TABLE II

ACCELERATION ON SAIL AS A FUNCTION OF TRANSFER TIME WHEN THRUST IS APPLIED TANGENT TO TRAJECTORY

Transfer Time (days)	g's at Earth	g's at Mars
80	13×10^{-5}	5.6×10^{-5}
100	10×10^{-5}	4.5×10^{-5}
150	6.9×10^{-5}	3.0×10^{-5}
200	5.2×10^{-5}	2.2×10^{-5}
250	4.1×10^{-5}	1.8×10^{-5}
300	3.4×10^{-5}	1.5×10^{-5}

THE APPLICATION OF NON-TANGENTIAL THRUST

From the foregoing equations, a sail tilt parameter, p, and hence the sail tilt angle, ϕ, may be computed, thus minimizing the sail area for a given trajectory (*i.e.*, for a given value of q). In general, these minima occur for tilt angles in the neighborhood of 30° to 40° with the optimum tilt angle increasing as β approaches 90°. Fig. 3 shows the sail area per unit weight plotted against the tilt angle ϕ for trajectories having β angles of 80° and 85°. It is immediately evident that sails sized for tangential thrust applications are excessive when compared to minimum sail areas, although the transfer times are slightly less. Fig. 3 also shows that the transfer time has a strong dependence upon the angle β and a weak dependence upon the angle ϕ. Thus, it is better to consider a trade-off between sail size and trajectory path than between sail size and sail tilt angle.

Fig. 4 shows that some control over flight time may be achieved by changing the tilt of the sail. By fixing a sail design point slightly above the minimum, the transit time may be increased or decreased by five to ten days with a small change in sail tilt. Of course, if the sail is originally set at minimum flight time for the given area and trajectory, then the transit time can only be increased by a sail tilt angle-change in either direction.

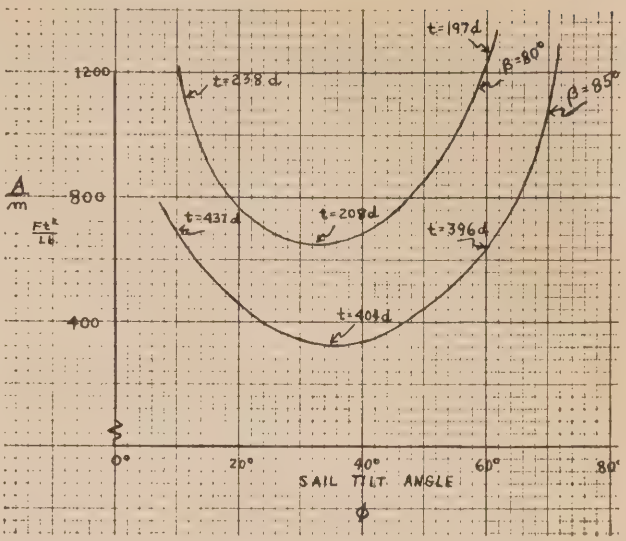

Fig. 3—Sail area required vs sail-tilt angle for trajectories from Earth to Mars.

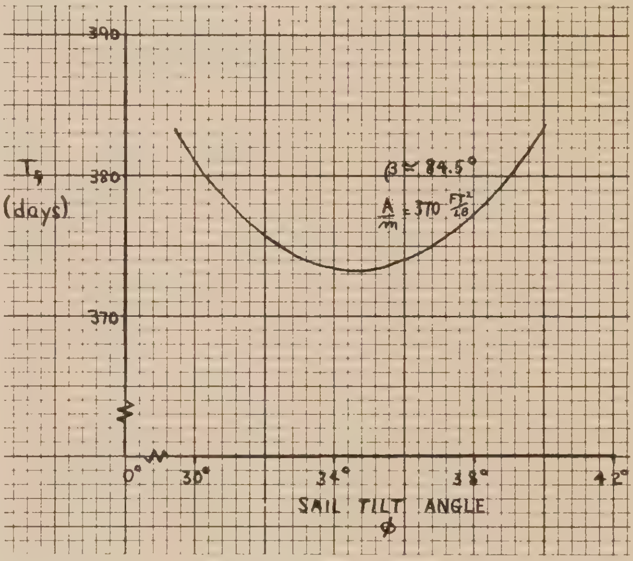

Fig. 4—Transfer-time vs sail-tilt angle, at constant sail area for trips from Earth to Mars.

SOLAR SAIL PROPULSION COMPARED TO CHEMICAL PROPULSION

Because the photon-powered vehicle has a very low acceleration capability (typically 10^{-4} to 10^{-5} g's), it cannot leave the Earth under its own power. Some additional energy must be added to inject the vehicle into a logarithmic spiral trajectory. The speed of a vehicle in a logarithmic spiral trajectory is nearly the speed of a vehicle in a circular orbit at the same distance from the sun, but with a change in direction. After the vehicle has escaped from the gravitational field of the Earth, an additional increment of velocity, ΔV (see Fig. 5), must be applied to turn the velocity vector into the logarithmic spiral velocity requirement, where

$$\Delta V^2 = V_E{}^2\left[\left(1+\frac{2q^2+2}{q^2+qp+2}\right) - 2\sin\beta\left(\frac{2q^2+2}{q^2+qp+2}\right)^{1/2}\right]. \quad (36)$$

If ΔV is applied after escape from the Earth, the total velocity budget needed to enter a logarithmic spiral is 6.97 mps (Earth escape velocity) plus ΔV. After escape

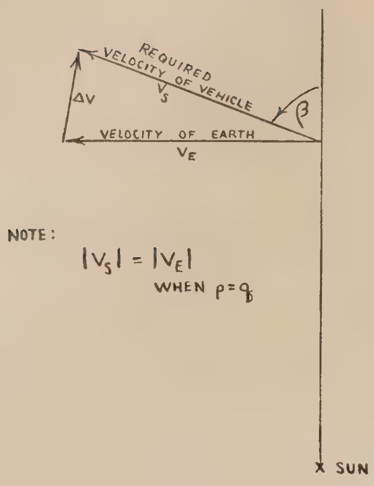

Fig. 5—Velocity coupling from orbital velocity to Earth to velocity of vehicle in log spiral.

the vehicle already has earth orbital velocity, and ΔV adjusts the direction. Fortunately, the burnout velocity, V_b, need not be the sum of 6.97 mps plus ΔV, if fuel is burned near the surface of the Earth. The minimum required burnout velocity (V_b) may be calculated by the following equation:

$$V_b^2 = 6.97^2 + \Delta V^2. \tag{37}$$

Then

$$\Delta V_n = V_b - 6.97, \tag{38}$$

where ΔV_n is the velocity increment needed, in addition to escape velocity, at burnout. Both ΔV and ΔV_b are listed in Table III.

TABLE III

COMPARISON OF SOLAR SAIL VEHICLE WITH A BALLISTIC VEHICLE FOR FLIGHTS TO MARS

Injection angle β	ΔV (mps)	V_b (mps)	Injection payload (pounds)	Sail weight (pounds)	Transfer Time (days)	
					Solar sail vehicle	Ballistic vehicle
75°	4.8	8.5	580	110	143	94
80°	3.2	7.7	860	110	208	125
85°	1.6	7.2	1100	76	404	not possible

The same ΔV_n may be used to inject a ballistic vehicle of the same weight into an interplanetary (elliptical) trajectory. As an example, assume that a 1200-pound vehicle is boosted to 6.97 mps near the surface of the Earth. Let ΔV_n be supplied by a chemical rocket which is part of the 1200 pounds. After burnout, the rocket is dropped and the remainder is designated as injection payload (IPL). For the photon-powered vehicle, the injection payload includes the weight of the sail.

A comparison of the times of flight for a photon-powered vehicle and a ballistic vehicle, injected into their respective heliocentric orbits with the same initial conditions, is also shown in Table III. The times of flight are longer for the solar-powered vehicle, and the useful payload is less since the sail weight is part of the injection payload.

Assuming a sail density of 2×10^{-4} lb/ft², the weight of the sail is listed in Table III. While these weights are not excessive, it can be seen that the controllable sail-area may limit the size of solar sail vehicles.

SOLAR SAIL WORK COMPARED TO ELECTRICAL ENGINE WORK

Assume a hypothetical electric engine which has a power output capability of 0.1 kw per second per pound of engine weight, and an efficiency of 70 per cent. After a determination of the optimum specific impulse for a particular mission is made, the mass ratio, power, and finally, the engine weight may be computed.

With the above engine set as a standard, a comparison between a solar sail and electrically powered vehicles is shown in Table IV. Here the sail-powered vehicle shows a payload weight advantage. It thus appears that in some instances the solar sail-powered vehicle is worthy of more consideration.

TABLE IV

COMPARISON OF AN ELECTRIC POWERED VEHICLE WITH A SOLAR SAIL VEHICLE

T_f (days)	Optimized specific impulse (seconds)	Injection payload (pounds)	Propellant for electric powered vehicle (pounds)	Solar sail weight (pounds)
150	6500	542	249	97
200	7500	822	300	100

ACKNOWLEDGMENT

The authors wish to thank Miss B. Cain, H. May, and Miss O. Helming for their able assistance in the generation and preparation of this paper.

Interplanetary Navigation*

G. M. CLEMENCE†

Summary—**The similarities and differences between interplanetary navigation and navigation on the earth are discussed. It is shown that in interplanetary space, position-fixing can be accomplished by a simple extension of the techniques already familiar to all navigators; but, when very close to the destination, other techniques are more suitable.**

INTRODUCTION

By interplanetary navigation is meant the art of getting a ship from one planet to another, particularly from the earth to the nearest planets, Venus and Mars, and back again. In many respects it resembles navigation on the earth. There are the same three phases: departure, midcourse, and arrival, each with its separate problems, and the navigator is interested in the same things, namely, his position, course, speed, and time.

There are also some important differences between interplanetary navigation and earthbound navigation. Most important of them is the force of gravity, which dominates all other considerations in all three phases of a voyage. At departure and arrival, considerable power is needed to overcome gravity; in midcourse, gravity is an important aid. Indeed, with proper planning, gravity can be made to provide all the transport required in midcourse, shipboard power being needed only for small changes in course, and for attitude control, thus achieving maximum economy of power at considerable sacrifice of time. For example, a voyage to Mars or Venus in free flight would require about half a year, which could be considerably reduced by using shipboard power for acceleration during the first half of the journey and deceleration for the remaining half.

Another important distinction is that whereas earthbound navigation usually involves a man on board, interplanetary navigation does not, at least after departure. It is beyond the capacity of any man, even with the assistance of a good calculating machine, to make the necessary observations, calculations, and decisions that are necessary for safe arrival, in the short time that is available for making them. The navigation system and control must be completely automatic. If a man is aboard, it is conceivable that he might be permitted to make a limited number of very general decisions, such as, for example, to circle his destination instead of landing, or to return home before reaching his destination, but any decision requiring much technical reasoning must be avoided, because it will not be practicable for him to acquire the necessary experience in advance of his first voyage.

THE GRAVITATIONAL FIELD

The gravitational field of the solar system is difficult (or impossible) to visualize accurately, but a rough two-dimensional analog of it may be easily conceived. Imagine a large circular sheet of thin elastic material stretched over a rigid horizontal hoop. Place a heavy weight representing the sun in the center of the sheet, which will then take a bowl-like shape; the shape of the plastic sheet represents the gravitational field of the sun. A small object placed anywhere on the sheet will roll at once into the sun, somewhat as a body would move in the actual solar system if released almost anywhere in it. Now take a marble representing Jupiter, 1/1000 as massive as the sun, and make it roll in a circle around the inside of the bowl, at such a speed that it neither spirals in to the sun nor climbs up to the edge of the bowl. The actual orbits of the planets differ slightly from circles, but not perceptibly so on a scale that could be reproduced for our model. In the model, the depression in the sheet caused by the weight of Jupiter represents the gravitational field of Jupiter, and must be thought of as extending over the entire sheet, quite deep at Jupiter itself and very shallow at moderate distances, but nevertheless perceptible all over the bowl. A small object now dropped on the sheet will usually roll into the sun as before, but if it happens to fall sufficiently close to Jupiter it will roll into Jupiter, or, if given the proper distance and velocity, may continue to roll around Jupiter, becoming a satellite. Jupiter goes once around the sun in 12 years.

One-fifth of the distance from the sun to Jupiter is the earth, 1/300 as massive as Jupiter, circling the sun once a year, with its gravitational field superposed on those of Jupiter and the sun. A little inside of the earth is Venus, of about the same size, and a little outside is Mars, about 1/10 as massive as the earth. Venus goes around the sun in 225 days and Mars in 687. Beyond Jupiter are Saturn and other planets, and inside of Venus is Mercury.

The three stages of the navigational problem on the sheet, limited to gravity alone, are as follows. At departure it is necessary to give a sufficient velocity to the ship, about 7 miles per second, to make it escape from the depression caused by the earth, and such a direction that it will take its own orbit around the sun, coming as near as may be to, say, Mars during its first trip around. A direct hit is not to be expected, because under the most favorable conditions the accuracy of aim required is much like aiming at a dime at a distance of 160 yards. Therefore, some midcourse guidance will be required. As Mars is closely approached, some deceleration will be necessary for a soft landing.

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* Original manuscript received by the IRE, November 23, 1959.

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CHARTING THE SOLAR SYSTEM

A chart of the solar system is as necessary for interplanetary navigation as one of the surface of the earth is for earthbound navigation. The solar system must be charted in three dimensions instead of two, and since the bodies in the system are all in rapid motion relative to one another, the chart takes an unconventional form. It consists of a timetable or *ephemeris* showing the coordinates of the sun and planets at such short intervals of time that they may be gotten for any instant by interpolation. These tables, together with a short list of the coordinates of a few dozen bright stars, suffice for all purposes. The construction of such tables has been one of the principal duties of the Naval Observatory for more than a century. They are presently available for some of the planets a century into the future, and for all the bodies of interest to the year 1972, with adequate precision for any interplanetary voyage.

Probably the most convenient system of coordinates to use is one of ordinary rectangular coordinates centered in the sun, with the astronomical unit as the unit of distance. The astronomical unit is very nearly the distance from the earth to the sun (about 90,000,000 miles) and it is more convenient than any other for interplanetary distances. In such a system, the actual coordinates of the stars would not be given. The stars are so remote that from any place in the solar system they may be regarded as fixed beacons in the sky, and their direction cosines are more convenient than the actual coordinates would be.

DEPARTURE

The departure of an interplanetary ship is in all respects similar to that of a multistage rocket with two exceptions. First, a great deal of calculation must be done in advance to determine the optimum orbit, which will depend very considerably on whether the midcourse is to be traversed under power or not, and which, in early voyages at least, will be planned so that the ship will travel the shortest practicable distance. The problem is one of compromising between power consumption and time required for the voyage, and a very great range of ways of making the compromise is possible. Having once decided on the orbit, the second exception appears: there is in general only one possible instant of time of departure when the conditions can be fulfilled. Of course, for times of departure very near the optimum one, only small increases of power and/or small increases in the duration of the voyage will be necessary. Probably a moderate compromise in a particular case would be one requiring variations of a few per cent in quantity of fuel and duration of the voyage. A typical departure schedule might read, depart between 22 and 23 hours on any night during the week of August 24, 1960. In such a case, provision would have to be made for varying the direction of departure by a few degrees depending on the date and on the time of day.

MIDCOURSE NAVIGATION

In order to reach Venus or Mars in free flight, it would be necessary to control the direction at departure to a few seconds of arc, and the velocity to comparable precision, say a part in a hundred thousand. Since it is not to be expected that this precision will be attained, it will be necessary to determine the position, course and speed, and to make alterations of course and probably of speed during the voyage. The more frequently these alterations are made, the smaller they need be, and the less total energy will be required for such purposes, up to the point where the alterations become so frequent as to be random in character.

Translated into astronomical terms, the determination of position, course and speed is equivalent to the determination of the orbit, and of the position of the ship in it. Broadly speaking, there are two possible techniques. The first is Doppler radar and ranging, which is best done from the earth, with a transponder in the ship, and is most useful during the first few days of a voyage, when the motion of the ship is principally away from the earth, that is, principally along the line of sight. The technique becomes useless when the ship is moving nearly at right angles to the direction of motion of the earth, as it will be during later stages of the voyage. In this case it is necessary to employ angular measurements, which can best be made from the ship itself, and which should be used at all stages of a voyage, provided the ship is not too close (say 100,000 miles) to the earth or to its destination.

Utilizing angular measurements from the ship, there is no reason why a continuous indication of position should not be obtained by completely automatic means, using trackers and computers within the ship, and communicating the results both to those on board and back to the earth. Course and speed can be obtained with all necessary precision by comparing positions obtained at different times, and these also can be calculated automatically.

The principle of position-finding in interplanetary space is as follows. Suppose that a planet is observed at some instant in coincidence with a star. It follows that the ship must be somewhere on a line joining the star and planet. If another planet is observed simultaneously in coincidence with another star, another line is established intersecting the first one, and the ship's position is at the intersection. In practice the problem is not quite so simple, because it is not convenient to observe coincidences of planets with stars, but the principle is easily generalized. What is done in practice is to measure the angle between a planet and a star in the same general region of the sky. The star is so far away that it may be considered to be infinitely distant. The observation then locates the ship on the surface of a cone having its vertex at the planet and its angle equal to twice the observed angle. A similar observation of another star and planet locates the ship on another cone, which in general intersects the first one in a curved line. In order to fix the position of the ship along this line, a third similar observation is needed (see Fig. 1). It is not necessary, however, to observe three distinct planets; two will do if a suitable choice of stars is made. Also the sun can be used in place of a planet. The planets that are nearer to the ship give more precise indications than distant ones do, and within the inner reaches of the solar system the most valuable objects will be Mars, Venus, the earth, and the sun, although Jupiter and Saturn may be used on occasion. It turns out that there are just enough suitable planets in the system to make the technique a convenient one.

For position-finding by angular measurements, it is not necessary to have a clock on board. A fourth observation of the same type as the other three suffices to determine the time with sufficient precision, since the four cones of position can intersect in a single point at only one instant of time. It will, however, probably be convenient to carry a clock, which need not be a very precise one; a clock keeping time to a few seconds a year is easily provided and is amply precise.

The position-fixing will be very rough by earthbound standards. In the middle of the voyage, errors of 20,000 miles will not be uncommon, but such errors will have no more serious consequences than errors of a mile do on the earth. They correspond to changes in direction of about a minute of arc, which is a convenient order of magnitude for effecting changes in course.

Knowing the position, course and speed, a calculation made on board will show whether the ship and its intended destination are traveling on courses that intersect or not, and whether they will arrive at the intersection at the same time or not. If not, further calculation will be required to show whether the course or the speed, or both, should be changed, and by how much. The calculations are elaborate ones using many significant figures, and cannot possibly be made in the required time without a good stored-program electronic calculator.

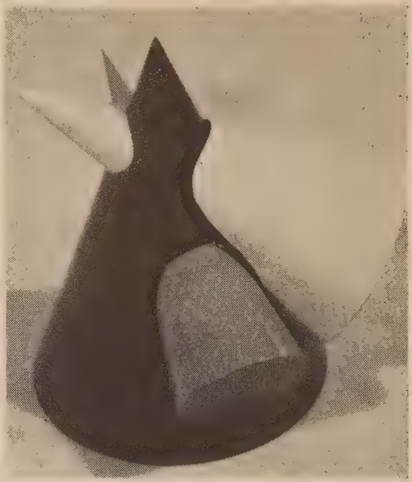

Fig. 1—Three cones of position showing (in black) lines intersecting at position of ship. (Official U. S. Navy photograph.)

ARRIVAL

As the destination is approached within say 100,000 miles, a different technique of navigation must be employed. Although angular measurements are ideal for position-fixing at great distances, it is not possible to rely on them when landing. At this stage, the distance and velocity of the ship relative to the landing field must be known with high precision, and it will be desirable to employ radar ranging and Doppler radar, using signals transmitted from the ship. It will be necessary to take into account the relative orbital velocity of the destination, and its rotational velocity as well, unless a landing is to be made at one of the poles. The rotational velocity of Mars is known already with enough precision, but the same may not be true for Venus. Venus is perpetually covered with dense clouds, and no permanent markings on the surface have ever been observed with certainty. Perhaps special observations at short range will be necessary for determining its rotational velocity.

Navigation Using Signals from High-Altitude Satellites*

ALTON B MOODY†

Summary—**If electronics can be satisfactorily applied to celestial navigation, a system having universal coverage without weather limitations might be produced. Radio stars are not a promising possibility, but the sun and moon are being tracked by the U. S. Navy Radio Sextant, AN/SRN-4, to provide limited coverage. Universal coverage might be achieved by the addition of artificial earth satellites. Satellites in orbits a few hundred miles from the earth might be used in some form of piloting system, but orbit-prediction problems, limited coverage by individual satellites, and computer complexities are serious obstacles to be overcome by such a system. A different approach would be to place three or four satellites in orbits at an optimum distance somewhere between 1000 and 12,000 miles from the earth to serve as artificial celestial bodies in a system that would be a natural evolution from traditional celestial navigation methods. A stabilized directional antenna operating with a receiver capable of accepting signals from both the satellites and the sun would provide angle measurement data both for fixing the position of the craft and also for establishing a north reference. The degree of sophistication of the user equipment would differ with requirements.**

INTRODUCTION

NOW that the novelty of artificial satellites of the earth has worn off, the question is logically being raised as to their practical utility for purposes other than pure research. Natural celestial bodies which have been available throughout recorded history may provide some guidance. These bodies, in addition to providing light and heat and serving certain other useful purposes, have been used for navigation to assist travelers on land, at sea, and in the air to fix their positions and determine direction.

Celestial navigation has been attractive because it provides universal coverage over the entire world with essentially uniform accuracy adequate to meet the requirements of the navigator. Its principal disadvantage has been its dependence upon clear weather. Other shortcomings have been the lack of a fully satisfactory horizontal reference for making the observations, and the need for lengthy computations to reduce the observations to positional information related to the observer.

Electronics has aided materially in the solution of these last two problems, but what of the larger problem of weather limitations? Here, too, electronics has had a significant role. Radar, loran, radio ranges of various types, Decca, the radio direction finder, and other electronic piloting aids have contributed significantly to the removal of the weather limitation. However, to a greater or lesser extent these aids are limited by geographical siting problems, propagation patterns, logistic considerations, vagaries of propagation over long paths within the atmosphere, ionospheric effects, the need for international cooperation, diplomatic considerations, antenna destruction by weather or future enemy action, the threat of possible countermeasures, lack of military security, and high installation and maintenance costs. Electronics has also been used to produce two excellent types of dead reckoning systems, Doppler radar and inertial, but these are not wholly adequate because, being dead reckoning systems, their results degrade with time and distance traveled.

Can celestial navigation and electronics be combined to produce a system having the universality of celestial and the all-weather capability of electronics, with essential freedom from the limitations encountered by present systems? This is a subject worthy of consideration.

ELECTRONIC CELESTIAL NAVIGATION USING NATURAL CELESTIAL BODIES

Discrete sources of cosmic radio energy, commonly called "radio stars," have been studied with this in mind.[1] Angle measurement would be utilized in the traditional manner of celestial navigation. However, the signal received from known natural sources is weak, and decreases rapidly as wavelength is decreased. As wavelength increases, the angular sensitivity of a tracking system decreases. Studies taking into account various considerations such as receivers, antennas, source characteristics, atmospheric attenuation, and refraction indicate an optimum wavelength region centered at about 4 cm. For a practical navigation system of suitable accuracy an antenna diameter of more than 15 feet would probably be necessary to overcome atmospheric emission effects. A considerable amount of research would be needed to accomplish this. Eventually such a system might evolve, but radio stars are not promising as a means of providing a satisfactory electronic celestial navigation system in the near future.

Both the sun and moon have been satisfactorily tracked by means of the Radio Sextant, AN/SRN-4, developed for the U. S. Navy by the Collins Radio Company. The installation aboard the *USS Compass Island* is shown in Fig. 1. Two optimum wavelength regions have been identified. At 8.7 mm the angular sensitivity of an antenna of given size is relatively great, and solar dynamic activity is not troublesome, but the

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* Original manuscript received by the IRE, November 23, 1959.

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[1] G. R. Marner, "Automatic radio-celestial navigation," *J. Brit. Inst. Navigation*, vol. 12, pp. 249–259; July/October, 1959.

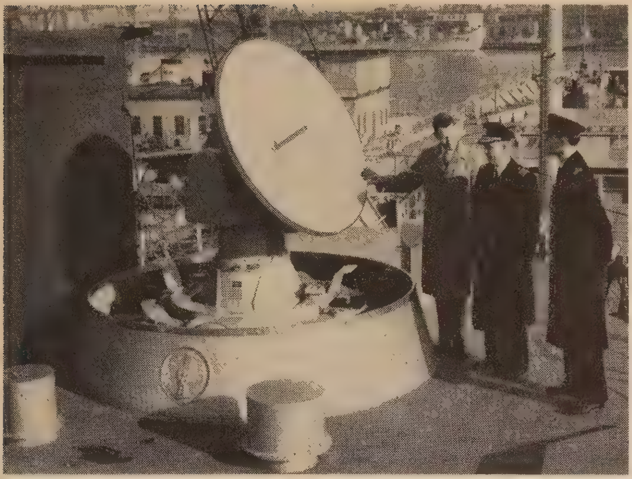

Fig. 1—Radio Sextant AN/SRN-4 (courtesy of Collins Radio Company). (Official U. S. Navy photograph.)

operation is adversely affected by rainfall. At a wavelength of 1.9 cm the system is affected less by severe rainfall, and an antenna only slightly larger than at 8.7 mm is needed. At wavelength longer than 2.0 cm, solar dynamic activity effects are great enough to be troublesome. Although the moon has been successfully tracked, as indicated, the inclusion of this capability adds considerably to the complexity of the system.

Although the sun and moon have been used successfully by the Navy, these bodies are not always available. The length of the periods when neither is available increases as latitude increases, becoming maximum at the poles, where intervals as long as two weeks occur during which neither body is above the horizon.

It is appropriate, therefore, that the possibility of using artificial earth satellites be explored to determine the practicability of using a modest number of them to provide a system that will meet navigational requirements at a price the user will be able and willing to pay.

Electronic Celestial Navigation Using Artificial Earth Satellites

The ability to place satellites in orbit and receive signals from them over a long period of time has been amply demonstrated. The experience with Sputnik III and Vanguard I are notable examples. There remain to be explored, however, the requirements for a navigational satellite, and the problem as to whether or not these requirements can be met at reasonable cost.

First, what are the parameters that might be measured? The possibilities can be summarized as

1) Distance and its time derivatives,
2) Altitude and its time derivatives,
3) Azimuth and its time derivatives.

The measurement of distance and its time derivatives is essentially a piloting problem, the position of the observer being established with respect to the satellite. Further, if the distance at nearest point of approach is determined, direction is also established and one obtains a fix. A fix might also be obtained by means of simultaneous distances from two or more satellites, or a running fix by two distances of the same satellite after a satisfactory change of azimuth.

One method of determining distance would be by direct measurement using primary radar. From a military standpoint this is not attractive because of the need for transmission by the user. The same problem would arise with respect to secondary radar using a transponder in the satellite. Additionally, a saturation problem might be involved if a large number of users interrogated the satellite at the same time. Jamming by a future enemy would not be difficult.

A more attractive method of determining distance would be by measurement of the Doppler shift in frequency of CW transmissions from the satellite. This method has been used successfully in the United States and the USSR to determine the positions of satellites from known positions on earth. The Doppler frequency change at any moment could be determined only if one knew the exact frequency of transmission, but if the variations of the Doppler effect throughout a passage of the satellite were measured and analyzed, knowledge of the exact frequency of transmission would not be needed, as long as it remained reasonably stable during the period of observation.

Analysis of the Doppler information to extract useful navigational information would require computational facilities of considerable complexity. Use of Doppler favors orbits relatively close to the earth. As the radii of orbits increase, the Doppler effect becomes smaller and less sensitive to the position of the observer. Also, unless stabilization or tracking is used, the antenna would have to be reasonably omnidirectional. This would favor relatively long wavelengths if adequate collecting area were to be provided with reasonable power. As wavelength increases, unpredictable ionospheric phase shifts and atmospheric refraction become a greater probability. If multiple frequencies are used to provide corrections, added complexities are encountered. In order to prove the feasibility of a satellite navigation system using Doppler techniques, it will be necessary to indicate solutions in the areas mentioned above and to demonstrate ability to predict orbits with an accuracy considerably better than attained to date. This problem is discussed in more detail later. Studies along these lines are presently being pursued under a U. S. Navy contract.

A completely different approach to the possible use of satellites for navigation, presently under study, is to consider them as celestial bodies and to use the traditional angle-measurement approach of optical celestial navigation. As commonly practiced, this involves measurement of the altitude (angular distance above the horizontal) of two or more bodies simultaneously, or of one body with a sufficient time separation of observations to allow for an adequate change of azimuth. Each observation establishes a circle of position with the geographical position of the body (the terrestrial position at which the celestial body is vertically overhead) as the center and the zenith distance as radius. A small portion of this circle in the vicinity of the observer is called the "Sumner Line," or line of position. The common intersection of two such lines fixes the position of the observer.

At the distances of natural celestial bodies, their change of apparent position is essentially that caused by daily rotation of the earth upon its axis. For moderate altitudes, this requires the availability of at least two celestial bodies for wholly satisfactory results. With a single body, a wait of several hours between observations permits introduction of unpredictable dead reckoning errors that can be intolerably large. At the faster rates of satellites, the running-fix principle is more attractive.

A single body might provide a celestial fix by simultaneous measurement of any two of the quantities, 1) altitude, 2) rate of change of altitude, 3) azimuth, and 4) rate of change of azimuth. Methods involving azimuth and rate of change of azimuth have been virtually unused because this information has not been available to the required accuracy. Likewise, rate of change of altitude of natural celestial bodies involves advanced averaging techniques. However, with the higher rates involved with artificial satellites, this parameter is worthy of consideration. One feature of using altitude and rate of change of altitude that is particularly attractive is that the two sets of curves involved are always orthogonal to each other, which is the ideal situation in celestial navigation. Whether rate of change of altitude can be determined satisfactorily without undue complexity of equipment has not been established.

It is well established, however, that navigation using simultaneous altitudes of two bodies, or successive altitudes of the same body, can provide a satisfactory navigation system without complicated averaging processes. Further, this method lends itself to hand computation methods which are well understood by navigators everywhere. The method is commonly used daily with natural celestial bodies. The use of satellites would require adequate electronic equipment for measurement of the parameters involved. No analysis of results would be needed. The computation required to convert the measured parameters to position of the observer, or to provide guidance, could be performed electronically where this is desirable without adding greatly to the complexity of the equipment.

Although details relating to exact procedures and specifications for almanacs and sight reduction tables have not been worked out, these are problems which differ in no important respects from those which have already been adequately solved for celestial navigation using natural celestial bodies.

This method, then, is a logical evolution of the celestial navigation commonly practiced today, and it involves no untried principles. Its success depends primarily upon the ability to predict future positions of satellites with sufficient accuracy, and since the size of the orbit is not critical, an optimum value can be found. The orbit problem is discussed in more detail later.

If angle measurement is to be used in a satellite navigation system, stabilization and a directional antenna will be needed. This requirement adds complexity and cost to the equipment, but poses no serious technical problems. If short microwaves are used, the Radio Sextant, AN/SRN-4, can be used with relatively minor modification. This equipment, already developed, includes satisfactory stabilization and a directional antenna. The use of this equipment would obviate the need for long feasibility studies and time-consuming developmental work. It would also permit utilization of the sun, and possibly the moon, to extend coverage and provide a system of limited availability if artificial satellites were to be eliminated either by natural causes, internal failure, or possible enemy countermeasures. The success of the Radio Sextant is due largely to the efforts of Drs. D. O. McCoy and Gene Marner, both of Collins Radio Company.

Stabilization and a directional antenna make possible a highly important north-reference capability not available in other methods. They also reduce the complexity of equipment needed in the satellites; this is an important consideration in view of their inaccessibility for service in the event of malfunction or failure.

ORBITS

The type of satellite navigation system selected is closely related to the orbit problem; this may well be found to be the controlling consideration. Questions of orbital predictability, coverage, and number of satellites required are basic considerations.

The predictability of satellites launched to date has not approached the requirements for navigation. The perigees of available satellites have all been within a few hundred miles from the surface of the earth. The nature and magnitude of the disturbances to such orbits have not been fully defined. It is well known, however, that unpredictable effects caused by lack of precise knowledge of the gravitational field of the earth and variable atmospheric effects have posed serious problems. Astronomers who have been close to the prediction problem of satellites launched to date are not optimistic of an early solution.

As orbits increase in size, the disturbing gravitational and atmospheric effects become progressively less pronounced. However, as orbit radius increases, perturbations caused by gravitational attractions by the various natural celestial bodies increase. At very large radii these disturbances become excessive and difficult to predict. This would indicate that there is some intermediate radius which will prove optimum from a prediction standpoint. This radius has not been established, but it will undoubtedly be measured in thousands of miles, in addition to the radius of the earth. This is in sharp contrast to the orbits of satellites launched to date, all of which have had perigees relatively close to the earth. When compared with these, the satellites in the optimum orbit can be considered "high altitude." These are the satellites anticipated in the title of this article.

An important consideration in determining the number of satellites needed is the coverage provided by one such body. At a distance of 400 miles from the surface of the earth, a satellite can be seen simultaneously over less than 5 per cent of the surface of the earth. This increases to about 10 per cent at a height of 1000 miles, 25 per cent at 4000 miles, about 35.5 per cent at 10,000 miles, and about 50 per cent at infinity. Fig. 2 shows the percentage of the earth's surface over which a satellite is observable at one time.

Another approach to the coverage problem is to consider the width of the belt in which a satellite can be observed during a passage around the earth. At 400 miles from the earth this is about 45°, at 1000 miles it is about 88°, at 4,000 miles about 120°, at 10,000 miles about 143.5°, and at infinity about 180°.

Where some form of distance measurement is involved, the belt within which the satellite can be effectively used for navigation might be somewhat less than the radio visible belt because of limitations in the distance at which distance measurement provides a satisfactory parameter.

If the running-fix principle is to be employed with a series of observations of a single body, it is desirable to consider the width of the belt in which the azimuth changes by some established number of degrees during a transit. If 90° is used as the minimum change in azimuth (90° between observations being the optimum), the belt is about 36° at 400 miles from the surface of the earth, 57° at 1000 miles, 101° at 4000 miles, and 134° at 10,000 miles. During one revolution of the satellite, the earth would rotate on its axis about 25° for a satellite at 400 miles, 30° for one at 1000 miles, 60° at 4000 miles, and 140° at 10,000 miles. Fig. 3 shows the widths of the radio belt, width of the belt in which azimuth changes more than 90°, and earth rotation during one orbital period for various orbits.

The faster motion of a satellite at low altitudes is an advantage to any method involving a time derivative, but it also imposes a more stringent time requirement. Thus, the time tolerance for an error of 0′.1 in subsatellite position is less than 0.03 second for a satellite 400 miles from the earth. This increases to nearly 0.035 second at 1000 miles, 0.067 second at 4000 miles, and 0.155 second at 10,000 miles. An error of 0′.1 in orbit prediction may be too large for a high accuracy navigation system.

An error in the height prediction introduces a parallax error which is significant where angle measurement is involved. Parallax error is maximum at the horizon and decreases to zero at the zenith. If a parallax error of 0′.1 can be accepted, the tolerance in height prediction is less than half a mile for a satellite at a distance of 400 miles from the surface of the earth, a little more than half a mile at 1000 miles, about 1.3 miles at 4000 miles, and

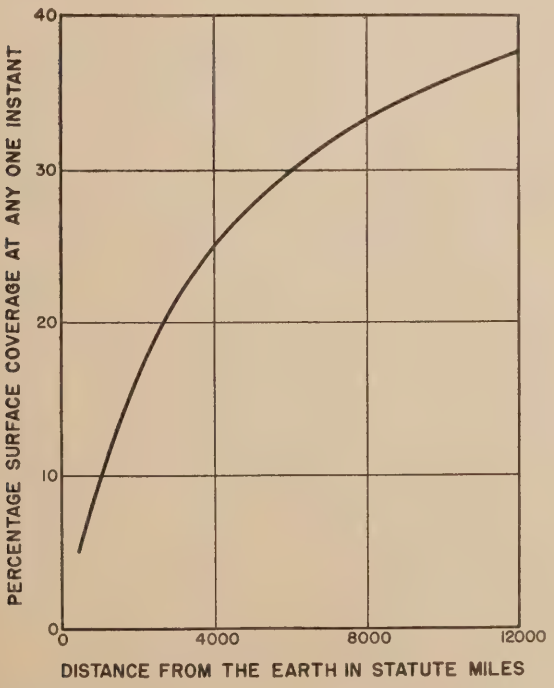

Fig. 2—Percentage of earth's surface in which a satellite can be seen at one time.

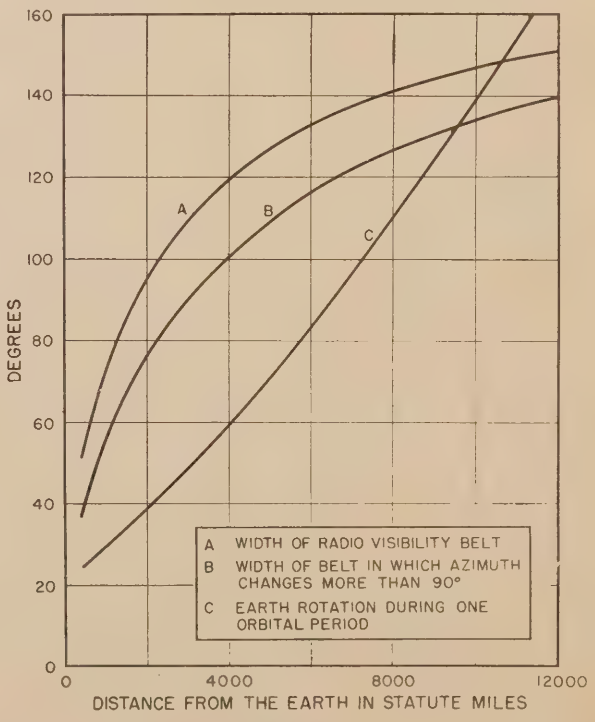

Fig. 3—Width of visibility belts and earth rotation during one orbital period.

a little more than 4.1 miles at 10,000 miles.

Thus, it appears evident that the problems of predicting future positions of satellites and providing adequate ephemeridal information are greater for satellites relatively close to the earth than at a distance of several thousand miles. Not only are small orbits most difficult to predict, but the accuracy requirements are greatest for these orbits.

The number of satellites required for a navigation system depends upon the parameters to be measured, the distance of the satellites from the earth, interrelationship of the orbits and the satellites in their orbits, and the duration and frequency of the intervals during which no fix is available. It appears evident from the geometrical considerations discussed earlier that for any type system, the number of satellites needed if large periods of unavailability are to be avoided is greater at orbits close to the earth then for those at a distance of several thousand miles.

If the system requires a relatively long period of observation to establish a fix, the number of satellites will be greater for a given fix frequency. The maximum needed would be for a system requiring satellites relatively near the earth and a full pass of a satellite to establish a fix. The minimum would be required for a system using high-altitude satellites and providing continuous fixing capability during passage of a satellite above the horizon.

The number of satellites needed for any system can be kept to a minimum by judicious selection of the orbits and the positioning of the bodies within the orbits. However, the value of this device is somewhat limited by the lack of capability to place a satellite precisely in a predetermined orbit. Because of differences in orbits, variations in precession and rotation of the orbits can be expected to nullify any planned relationship of position of satellites with respect to each other. The one element of the orbit that can be controlled with sufficient accuracy is inclination to the equator. It appears from a preliminary study that a family of orbits at progressive angles of inclination will best serve the needs of any type system.

If infrequent periods of nonavailability of several minutes is acceptable, with occasional periods of more than an hour, a preliminary investigation indicates that a high-altitude system with three to four satellites can provide satisfactory coverage. The coverage can be further improved if the system can also utilize natural celestial bodies. If the ability to reduce differences in the launching of satellites in predetermined orbits is demonstrated, the number of satellites can be decreased.

Any statement of the number of satellites needed for a given system should be evaluated in terms of the coverage it provides and its dependence upon capabilities theoretically possible but not yet demonstrated.

One final consideration relating to the size of the orbits concerns the tracking to provide ephemeridal data. Both optical and electronic tracking are probably desirable. The required number of tracking stations decreases with the distance of the satellite from the earth because of the greater area over which such satellites can be seen. At distances of only a few hundred miles from the surface of the earth, and also at distances at several tens of thousands of miles from the earth, the unpredictable nature of the perturbations would require that a closer watch be kept on the satellites.

Thus, all factors favor an orbit that avoids both extremes of distance from the earth. While the limits of the desirable range of orbits have not been definitely established, preliminary study from available data seems to indicate that the optimum distance lies somewhere between about 1000 miles and 12,000 miles from the surface of the earth. Use of this range would make possible the development of a system utilizing short microwaves so that the sun and possibly the moon might be used with the satellites to increase coverage. Such a system would be a natural evolution—actually a relatively short step—from systems already well developed.

The use of satellites in orbits thousands of miles from the earth appears to preclude the use of distance and its derivatives as the primary method of navigation by satellites. However, there are so many areas of uncertainty yet to be resolved if any practical navigation system using satellites is to evolve, that it is premature and unrealistic to pursue any one possibility to the exclusion of others until a clear superiority is demonstrated. The optimum system might even prove to be one providing both piloting and celestial capabilities, perhaps with somewhat overlapping ranges of application.

The High-Altitude Satellite

What are the requirements for a high-altitude satellite to meet the needs of a navigation system based upon angle measurement and possibly its time derivatives, and providing high-accuracy north reference?

Perhaps the first consideration is one of wavelength. It has been pointed out previously that use of short microwaves will permit use of the sun and possibly the moon to augment the coverage of artificial earth satellites and to provide partial coverage if satellites should become unavailable. However, considerations of the satellite system itself favor a short microwave frequency to provide adequate directivity in the user's receiving antenna, without an unsatisfactorily large antenna. The use of short microwaves increases the transmitter power requirements over what they would be in the UHF and VHF region, but these requirements are not excessive.

The use of short microwaves avoids the major propagation difficulties related to frequency instability and refraction as the signals pass through the ionosphere and lower atmosphere of the earth. Studies in this area carried out on Navy contracts have yielded sufficient information to conclude that this will not be a problem, as it can be expected to be if longer wavelengths are used.

The function of the transmitter in the satellite would be to provide a CW signal of adequate power for tracking. Since it has no other function, it can be of relatively simple design, enhancing the probability of a long, useful life.

Batteries, solar cells, fuel cells, and thermionic converters are possible power sources, but a combination of solar cells and batteries appears most attractive at this time. This is a proven combination. If the protective covering of the solar cells can be omitted, as seems probable, a considerable saving in weight can be effected. Some form of nuclear power may eventually be available for use in satellites.

If the orbit were exactly circular, and the satellite always maintained the same orientation with respect to the earth, the transmitting antenna could be shaped so that all users within the entire area of illumination on the earth would receive the signal with equal intensity. To achieve this would require a launching capability beyond that anticipated in the near future, and satellite stabilization about at least two axes. Even if successful stabilization is achieved, its use would add complexity and increase the probability of failure. A realistic approach is the use of an antenna with a pattern as nearly omnidirectional as possible. Circular polarization is desirable to avoid polarization error. The design of a suitable antenna is reasonably straightforward and no major problem would be anticipated in this area.

The weight of the transmitter, with adequate protection against vibration and shock during launching, and with suitable provision for removal of heat from the satellite during operation, should be within the capability of available launching devices and probably not more than 30 to 50 pounds.

User Equipment

The size and complexity of the user equipment for a celestial navigation system based upon CW signals from high-altitude satellites would depend upon the parameters to be measured, the acceptable period of time between fixes, the accuracy requirements, and the degree of sophistication desired in the readout. One feature of the use of relatively simple high-altitude satellites is that a wide choice of user equipment capability is possible with the same signals. This might vary from relatively simple equipment providing altitude and azimuth of moderate accuracy for hand computation, as with traditional celestial navigation, to highly complex equipment providing continuous position information or actual guidance according to a predetermined schedule. There is no reason to doubt that accuracy requirements can ultimately be achieved by means of such a system.

The first equipment could logically be expected to be an evolutionary development of the Radio Sextant, AN/SRN-4. There are two major components of this instrument. One is the tracking unit, consisting of the antenna and its scanning mechanism, the receiver, the tracking servos, and the angle readout system. The other major component is the Schuler-tuned stabilization system and north reference.

The properties of the receiving system, of course, are closely related to the transmitter power requirements. In satellite tracking, the transmitted power requirement can be kept to a minimum by the use of very narrow bandwidth. The phase-lock type receiver, first developed by the Jet Propulsion Laboratory for missile tracking purposes, offers a promising solution. In contrast, sun tracking involves very wide RF bandwidth. Consequently, a receiver designed for tracking both artificial satellites and the sun should have the capability of operating in both the narrow-bandwidth phase-lock mode and the wide-bandwidth radiometric mode. A number of components could be common to both modes of operation. Since the phase-lock frequency tracking loop is of optimum design to phase-track an incoming signal accurately, it provides the optimum method of extracting the Doppler signal, if this proves desirable.

A time standard of such accuracy that only occasional resetting by means of time standard broadcasts appears feasible.

The readout system to provide altitude and azimuth would be designed in accordance with accuracy requirements of the individual system.

As pointed out earlier, the complexity of the user equipment can vary between wide limits to meet different requirements. The simplest equipment would provide only altitude and azimuth for use in any manner that such information obtained optically is used. To this might be added a suitable computer with the capability of determining a fix by the running-fix principle, simultaneous observation of two or more bodies, or by altitude and rate of change of altitude. During the relatively brief and infrequent periods when a fix would not be available, the dead reckoning might be maintained by hand plot, hand computation, mechanical dead reckoning equipment, or by a more sophisticated system such as Doppler or inertial, according to requirements. Many of the elements of a high-grade inertial system would already be available within the receiving and stabilization system. The ultimate system would have the added capability of providing guidance in accordance with a previously inserted track and time schedule.

The system discussed would be suitable for use aboard a surface ship. It could also be used by a submarine, with the requirement that a parabolic antenna of moderate size be exposed periodically above the surface for brief intervals to obtain a fix. Between fixes, positional information would be provided by a high-grade, built-in inertial system. Aircraft and even missiles might be able to use the system, perhaps with some loss of accuracy to meet space and weight requirements.

CONTRIBUTIONS OF HIGH-ALTITUDE SATELLITE SYSTEM

Certain contributions might be expected from a high-altitude satellite navigation system of the type discussed. These are summarized as follows:

1) Continuous all weather position-fixing capability with universal coverage of uniform accuracy.

2) A continuous north reference in all weather.

3) Great flexibility in user equipment to meet different requirements.

4) High potential accuracy.

5) A passive system without ground-based transmitter problems. No transmission of any kind would be required from the surface of the earth.

6) A virtually jam-proof system.

7) A system combining use of artificial earth satellites with at least one natural celestial body to provide flexibility, extend coverage, and reduce the possibility of successful countermeasures by a future enemy.

8) Maximum utilization of satellites by using orbits at such distance that a minimum number would be needed, and these having a small number of relatively simple, reliable components to reduce obsolescence and increase useful life.

9) Limited ground facilities required. Because of the high, stable orbits, the only ground facilities required would be launching equipment, one radio and perhaps three optical tracking stations, and orbital computation and dissemination facilities. None of these would be of great complexity with the possible exception of the radio tracking station, and a suitable one is already in existence in the U. S. Navy-owned Feather Ridge station in Iowa.

10) The system could be provided as a short, orderly evolution of methods and equipment already developed, using principles in common use daily by navigators everywhere.

CONCLUSION

A preliminary study indicates that the development of a celestial navigation system using a small number of artificial earth satellites at an optimum distance expected to be somewhere between 1000 and 12,000 miles from the surface of the earth is feasible, and that such a system could be developed as a logical evolution of traditional celestial navigation and the Radio Sextant, AN/SRN-4, developed for the U. S. Navy for use with the sun and moon. It is entirely possible that the cost of development and maintenance of such a system, particularly if use is made of natural celestial bodies, would be less than that of a ground-transmitter system providing world-wide coverage.

If the need for a navigation system based upon signals from satellites is established, it would appear most logical to utilize the advantages of relatively high-altitude stable orbits and the work already done in developing the Radio Sextant and studying short microwave propagation through the atmosphere, rather than to pursue development of a system of more uncertain future. However, it is premature to rule out other possible methods of utilizing satellites for navigation until a clear superiority is demonstrated.

The opinions or assertions in this paper are those of the author and are not to be construed as official, or reflecting the views of the Department of Defense, the Navy Department, or the naval service at large.

A Satellite Doppler Navigation System[*]

W. H. GUIER[†] AND G. C. WEIFFENBACH[†]

Summary—**It is shown that a satellite Doppler navigation system can provide navigation to at least one-half mile accuracy from a single pass of a satellite, provided that proper use is made of the full Doppler curve. While not extensively discussed, a satellite Doppler navigation system is presented which conveniently provides navigators with all necessary inputs for position calculation, including up-to-date orbital data. The main body of the paper presents the results of a comprehensive error analysis which proves the feasibility of achieving navigational accuracies of one-half mile using such a system under realistic conditions.**

I. INTRODUCTION

In late 1957 and early 1958, the authors made a study of the feasibility of tracking satellites utilizing only the Doppler shift of radio signals transmitted from the satellite.[1] These studies indicated that, when properly utilized, each segment of the received Doppler curve provides useful information about the track of the satellite, and that in order to gain the maximum information from the Doppler data, the data should be used in a direct calculation of the six orbit parameters rather than used to compute intermediate parameters such as the slant range and time of closest approach. With this approach, and utilizing all of the Doppler curve for determining the track of a satellite (orbit elements), it was found that a single Doppler curve, received during a single pass of the satellite by a single receiving station, was sufficient to determine the orbit of the satellite to reasonable accuracy.

Table I indicates the results of a determination of the orbit of Sputnik I from a single Doppler curve.[2] In determining this orbit, the theoretical equation for the Doppler shift including ionospheric refraction effects was written as a function of the six orbit elements and two more parameters representing, respectively, a "vernier correction" to the satellite's transmitter frequency and a parameterization of the electron density of the ionosphere. The eight parameters were then varied until the theoretically computed Doppler shift agreed (in the "least squares" sense) with the experimental Doppler shift received from the 20-mc transmitter of Sputnik I. For comparison, the values of the orbit elements determined by two British agencies are given.[3,4] The British orbital data was believed to be the most accurate data available for Sputnik I at that time, and was compiled by the British from many sets of data including both interferometric and Doppler data. For this pass, it can be seen that surprisingly accurate values for all six of the orbit elements were obtained.

TABLE I

ORBITAL DATA
SPUTNIK I—20 MC

Estimated experimental error:	±4 cps
RMS fit to data:	±1.6 cps
Approximate ground range:	73 statute miles
Minimum angle of arrival from horizon:	20°
Time of closest approach:	23:47 GCT, October 21, 1957
Latitude of receiver:	38°41′N
Longitude of receiver:	75°59′W

Orbit Element	Doppler Determination	Reference 3	Reference 4
Period	95 minutes 38 seconds	95 minutes 36 seconds	95 minutes 34 seconds
Eccentricity	0.053	0.053±0.001	0.048±0.002
Inclination	64° 10′	64° 40′±10′	65°
Argument of perigee	43° 30′		
Latitude of perigee	38° 20′ N	36°±3° N	40.9° N
Longitude of ascending node	289°	291.6°±0.3°	

These values for the orbital elements were taken from References 3 and 4 and were given for October 15. Using their values for the secular variations, the values for October 15 were extapolated to October 21 for purposes of comparison.

Clearly, the constraint on satellite tracking that only a single Doppler curve is to be used is not appropriate if the main objective is to determine the orbit of a satellite accurately. This constraint was imposed solely to illustrate the large amount of information that can be obtained from a single Doppler curve. However, if the problem inverse to satellite tracking is considered, namely determining the location of the receiving station assuming a known satellite orbit (navigation), the ability to use a single Doppler curve becomes highly significant, since then a "navigation fix" can be obtained every time a satellite passes within range of the navigator. Furthermore, since navigation requires determining only two parameters (latitude and longitude) instead of the six orbital parameters of the satellite, a very large increase in the accuracy of the measurement can be expected.

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[*] Original manuscript received by the IRE, November 23, 1959. This work was supported by the Department of the Navy, Bureau of Ordnance, under Contract NOrd 7386.

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[1] W. H. Guier and G. C. Weiffenbach, "Theoretical Analysis of Doppler Radio Signals from Earth Satellites," Applied Physics Laboratory, The Johns Hopkins University, Silver Spring, Md., Bumblebee Series Rept. No. 276; April, 1958.

[2] "Letters to the Editors," *Nature*, vol. 181, p. 1525; May 31, 1958.

[3] Staff of the Mullard Radio Astronomy Observatory, Cambridge, Eng., *Nature*, vol. 180; 1957.

[4] Staff of the Royal Aircraft Establishment, Farnborough, Eng., *Nature*, vol. 180; 1957.

Such an approach to navigation was suggested in early 1958 by Dr. F. T. McClure. Shortly thereafter, initial studies on the expected accuracy of surface navigation, utilizing the radio Doppler shift in a manner completely analogous to the above example of Doppler tracking, indicated that this method could result in navigational accuracies of better than one-half mile.

In the present report, the main emphasis is placed upon the feasibility of achieving Doppler navigation fixes to an accuracy of one-half mile rather than upon the design and development of such a navigation system from the over-all system point of view. However, for purposes of orientation and background information, Section II contains a brief description of a satellite Doppler navigation system which adequately supplies the proper inputs to the navigator, such as orbital data. The main body of the paper is contained in Section III, which presents the results of various feasibility studies of Doppler navigation within the purview of the system as outlined in Section II. This section includes an analysis of pertinent sources of error including bias errors that are not of a statistical nature. Section IV contains a summary of the results and some comments on the use of such a system for navigation.

II. Elements of the Navigation System

An operational Doppler satellite navigation system should consist of 1) a network of satellites in orbit about the Earth at altitudes optimum from the standpoint of accuracy of both satellite tracking and of navigation, 2) a network of stations supplying tracking data to a computing complex for maintaining accurate ephemerides of the network of satellites, 3) a means for supplying to individual navigators the ephemeris of each satellite, and 4) independent navigating gear designed to receive the Doppler data from the satellite and to determine a navigational fix from these data.

The number of satellites that are required and the orientation of their orbits depend upon the maximum allowable time interval between opportunities for obtaining a fix. One satellite in an approximately circular polar orbit at an altitude of 400 nautical miles provides, anywhere on the Earth, the opportunity to obtain a navigational fix at least twice a day. It can also be shown that four satellites, in circular 400-mile orbits, can provide sufficient coverage for most of the Earth to obtain a navigational fix at intervals of about one and one-half hours. The altitude of the satellites should be sufficiently high to be little affected by air drag, in order to guarantee sufficient lifetime in orbit and to insure the capability of accurate tracking in the presence of the random variations in drag that would be troublesome at lower altitudes. On the other hand, for any given pass of the satellite, the accuracy of the navigation fix decreases with satellite altitude. Furthermore, Doppler data covering all of a satellite pass is required to obtain the maximum accuracy of a navigational fix. The total time that the satellite is visible increases with altitude, thereby increasing the time necessary to get sufficient Doppler data. Satellite altitudes between 400 and 500 nautical miles appear to be about optimum.

Each satellite would radiate very stable CW signals from which the Doppler shift would be measured by the navigator. In Section III it is shown that frequency stabilities of the order of 1 part in 10^8 are required. It is shown that if the Doppler shift is received simultaneously on two frequencies, a continuous real-time correction for ionospheric refraction can be made that does not require prior knowledge of the electron density profile. Frequencies in the 200- to 400-mc region appear to be satisfactory for providing sufficiently accurate refraction corrections and yet are not so high as to preclude the use of transistorized oscillators and transmitters. Finally, it can be shown that a transmitter power of about 100 milliwatts at these frequencies can give ample signal strength on the ground with simple antenna systems (such as a vertical dipole over a ground plane).

It would be highly desirable to provide the ability for each satellite to give the navigator its own ephemerides. Consequently, each satellite should contain a memory which would receive from an injection station on the ground its most recently computed orbital parameters and/or ephemeris. Thereafter, until new orbital data is injected, the satellite orbits around the Earth transmitting on two very stable harmonically related frequencies, and periodically reads out the injected orbital data from its own memory. Besides being a convenient method for identification and a supplier of orbital data to the navigator, the use of a satellite memory allows very frequent updating of the orbit. No matter how accurately the forces acting on the satellite are known, the accuracy of a computed satellite ephemeris decreases with the length of time that it is predicted into the future. With the use of such an injection station—satellite memory system—it becomes feasible to update the orbit of each satellite twice a day, which may be required to maintain satellite ephemerides to an accuracy compatible with one-half-mile navigation accuracy. Furthermore, since the ephemerides need cover only relatively short time intervals, complete minute-by-minute listings of satellite positions can be stored without the memory's weight and size becoming a burdensome factor.

Finally, since the stable oscillator in the satellite can be used as a clock, and the satellite memory can be used to store time corrections to this clock, as well as orbital data, the satellite can also transmit a time-synchronizing pulse and a correction to this time pulse. In this way the navigator (or any receiving station) can be supplied an accurate time standard on a world-wide basis. With the addition of the time standard, the injection station monitors the time pulses from the satellite, and determines a time correction with reference to some accepted standard. The injection station then transmits to the satellite twice each day the latest orbital data received from the computing center and the digitalized time correction. By now, the navigator receives during any single satellite pass all the inputs required for accurate navigation. He receives Doppler data on two harmonically related frequencies, from which refraction-corrected, or "vacuum," Doppler data can be obtained; he receives an accurate time check from which his own frequency and time standards can be calibrated; and finally, he receives the necessary orbital data, from which, together with the Doppler curve, he can compute his position.

Clearly, the accuracy of the satellite orbital data must be compatible with the requirements of navigational accuracies. Since the navigation satellites described above transmit all data necessary to perform Doppler tracking of the satellite, it is natural that the tracking system utilize the Doppler shift for computing the satellite orbit. The authors have reported elsewhere on the ability of a network of Doppler receiving stations to supply data for tracking satellites to an accuracy better than one-half-mile.[1,5,6] Presently it appears that no more than ten tracking stations are needed to supply ample data for updating the orbit every twelve hours, and the degree to which fewer stations can be used is only dependent upon the state of knowledge of the forces acting on the satellites.

Basically, the navigation gear required to receive the satellite signals and compute the navigator's position consists of a dual frequency receiver, a mixer to combine the two received frequencies for elimination of the refraction effects in a manner outlined in Section III, instrumentation to reduce the Doppler data to digital form, and a computer to determine the position of the navigator that provides a best fit between the received Doppler data and the theoretically computed Doppler shift. The sophistication of the computer can vary from the one extreme of hand calculations when lower accuracy is sufficient and time is available, to highly accurate, high-speed special-purpose digital computers for supplying the final navigational fix in printed form, essentially as soon as the pass of the satellite is complete.

In summary, a typical sequence of operations that might occur in an operational Doppler satellite navigation system is outlined as follows.

1) Tracking stations receive, reduce, and record in coded digital form, a vacuum Doppler curve for any pass of any satellite within receiving range (above the horizon). This information is transmitted to the computing center by, for example, commercial telegraph or TWX.

2) The computing center uses the vacuum Doppler data from many such passes for each satellite to calculate oribital data at 12-hour intervals for nominally one day in advance. This information is transmitted to the injection station.

3) Nominally twice a day, as each satellite passes within range of the injection station, the station transmits the orbital data and time correction to the satellite. These signals first erase the satellite memory unit and then read in new orbital parameters and a new time correction. Injection of data for a full day, at 12-hour intervals, provides the requisite accuracy of the orbital data and time correction, and provides for one failure to inject without incapacitating that satellite.

4) The satellite retransmits data received from the injection station once each minute, otherwise the two harmonically-related frequencies are transmitted continuously and unmodulated.

5) A navigator need only turn on his receiving equipment at a time when a satellite is due to pass within range. His equipment receives and records the vacuum Doppler data. From these data and with time and frequency corrections supplied by the time standard from the satellite, the navigator's latitude and longitude are computed.

The above section has attempted to outline very briefly the over-all concepts and functions of a satellite Doppler navigation system. In Section III, some of the details of the computing procedures necessary to obtain the latitude and longitude are presented when they are pertinent to the error analysis of the navigational fix. Other than to note that all equipment and hardware are well within the present state of the art, no details of the instrumentation are discussed in this report. Some aspects of the instrumentation are discussed in other papers appearing in this same issue.[7]

III. PROOF OF FEASIBILITY AND ERROR ANALYSIS

When the satellite orbit is known, a measurement of the Doppler curve in the vicinity of zero Doppler shift allows a determination of the time and the line-of-sight range to the observer at the point of closest approach. Consequently, the position of the navigator could be determined relative to the satellite orbit and, hence, his position on the Earth. The fact that the Doppler shift caused by motion of the satellite transmitter contains this information is well known. This principle has been used for years to determine the miss distances of CW homing missiles, and satellite tracking as well as navigation proposals have been made utilizing this principle. What has not been generally recognized is that by a more generalized and sophisticated analysis,

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[5] W. H. Guier, "Numerical computing problems in the Doppler tracking of near earth satellites," Proc. Meeting Math. Committee USE Organization, San Francisco, Calif.; August 1, 1958.

[6] W. H. Guier and G. C. Weiffenbach, "The Doppler determination of orbits," Proc. Natl. Aeronaut. and Space Admin. Conference on Orbit and Space Trajectory Determination, U. S. Naval Research Laboratory, Washington, D. C.; March 12, 1959 (in press).

[7] G. C. Weiffenbach, "Measurement of the Doppler shift of radio transmissions from satellites," this issue, p. 750.

information contained in the whole of the Doppler shift can be extracted to yield navigational accuracies competitive with the best existing navigation systems.

Two factors contribute to the accuracy which can be achieved by satellite Doppler navigation. The first is the well-known fact that frequency and time are two of the physical variables most readily measured with very high precision. The second factor, and this is the one that appears to have been largely overlooked, is the fact that there is tremendous redundancy in the information contained in the shape of the entire Doppler curve. The position of the navigator can be determined not only from the time and slope of the curve at the point of maximum slope, but also from a comparison of the Doppler shift at any two points on the curve. Thus, in principle, each pair of data points on the entire Doppler curve can be considered to provide a determination of the navigator's position and each of these determinations is more or less statistically independent. In practice, the optimum use of this redundant data is accomplished through the employment of curve fitting techniques such as the method of least squares.

The above, somewhat idealized, picture is, of course, true only when the errors are statistical in nature. Accuracy can be gained by adding more and more data points only up to the point where unknown biases in the data produce errors comparable to the accuracy obtained by using redundant data. For this reason, considerable emphasis has been placed on error analyses which include errors of a nonstatistical nature such as frequency drift, ionospheric refraction, etc.

It is impossible within the scope and length of this paper to report in detail on all the error studies that have been made to date by the authors and their colleagues. Consequently, reporting of results has been limited to those studies which lend understanding to the present approach to satellite Doppler navigation, establish the theoretical feasibility of obtaining accuracies to better than one-half mile, and exhibit sources of error that place limitations on the quality of instrumentation that is necessary. In Section III-A, the probable error arising only from errors of a statistical nature is given as a function of the ground range. In Section III-B various possible errors of a nonstatistical nature are considered.

A. Errors Contributed by Random Noise—Ultimate Accuracy

If one assumes that all the factors which might contribute to systematic or biasing errors can be accounted for, the accuracy of the system is only limited by the random errors arising from experimental noise. Consequently, an error analysis was performed in which all sources of error were ignored except the fundamental experimental random noise—the underlying thought being that the accuracy achievable under these conditions should roughly indicate the ultimate accuracy of the system.

Since Doppler navigation is based upon a frequency measurement, experimental noise appears as random errors in the measured frequency as a function of time. Estimates indicate that for a satellite at a 400 mile altitude with transmitter powers of about 100 mw, the RMS frequency error for any given statistically independent data point should be less than 0.5 cps at 100 mc, or about two to three parts in 10^9. This estimate was made assuming that "white" frequency noise existed and that the circuit time constants were such that a statistically independent data point could be taken once every second. However, the analysis given below did not utilize the maximum number of data points allowable under this assumption because 1) the maximum number of data points is so large (between 600 and 800) that computation methods available at the time were not adequate to handle so much data in a reasonable computing time, 2) approximate scaling laws exist for estimating the error for any number of data points, once the computations are performed with sufficient data points to provide a valid sample of the noise, and 3) it was not known at the time of the analysis what the autocorrelation time of the frequency noise would be in practice, and to be conservative, only data points separated by more than ten seconds were considered statistically independent. The results of the error analysis made under the conditions stated above will now follow.

The equations for the Doppler shift, as a function of the navigator's position, transmitter frequency, and time, are given in the Appendix. If the navigator is moving relative to the Earth during the time of the satellite pass, his position and his navigation error must be carefully defined. The main emphasis in this report is placed upon surface navigation (ships at sea), and therefore, the navigator's velocity is low and should be known with reasonable accuracy. Consequently, the navigator's position is defined to be his geodetic latiude and longitude at some chosen time t_0 during the pass of the satellite. With this definition, the Doppler shift has been written in the Appendix in terms of the quantities

ϕ_0, λ_0 = geodetic latitude and longitude of the navigator at the time t_0,

$\delta\phi(t), \delta\lambda(t)$ = change in latitude and longitude of the navigator during the pass time of the satellite relative to ϕ_0 and λ_0.

It was assumed throughout, unless otherwise stated, that $\delta\phi(t)$ and $\delta\lambda(t)$ contained negligible error, and that the navigation error was defined to be the error resulting in ϕ_0 and λ_0.

The error analysis was divided into two parts. First, a theoretical study was made based upon the usual techniques of curve fitting analysis. In this analysis it was assumed that about 50 data points were used, and the RMS frequency error was chosen to be 5 parts in 10^9. The results of this analysis are indicated in Fig. 1 as the solid, dashed, and dash-dot curves.

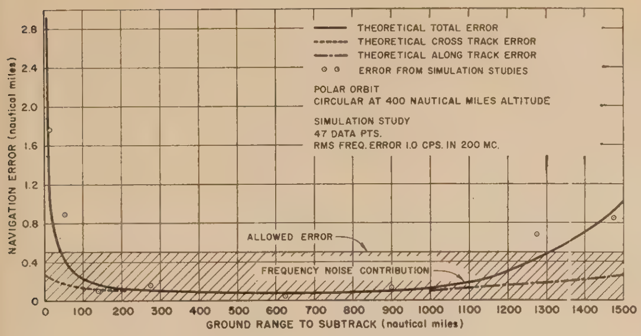

Fig. 1—Contribution of frequency noise to navigational error, as a function of ground range.

Second, a simulation was made in the following way. The expected Doppler frequency curve was computed assuming some position (ϕ_0 and λ_0) for the navigator. From this "theoretical" Doppler curve, 47 data points were chosen and random numbers, representing experimental noise, were added to the theoretical data to form synthetic experimental data. The magnitude of the noise was chosen to be the equivalent of a frequency error of about 5 parts in 10^9. Then, forgetting the position initially chosen for the navigator, his location was estimated to be that value of ϕ_0 and λ_0 which produced the least squares fit between the theoretical Doppler curve and the synthetic experimental data. In this way, the error in position introduced by the experimental noise could be estimated through a direct simulation of the navigator's computations and demonstrated that in practice computing procedures could be designed to achieve the surprisingly low error that is possible. The results of this simulation are indicated as circled dots in Fig. 1.

The results presented in Fig. 1 show the general characteristics that have been found in all error studies where only random noise is present. First, it can be seen that the error for most ground ranges is sufficiently low so that random noise cannot be a significant factor in achieving navigational accuracies of one-half mile. Second, in the few samples tried where synthetic data were used and actual navigation computations performed, the results agree quite well with the theoretically estimated error, lending confidence to the computer programs designed for navigation. Third, the navigational error becomes large at ground ranges such that the satellite appears above the horizon only for short times, and also at small ground ranges where the satellite passes nearly overhead. This is as expected since 1) when the satellite is always on the horizon, the determination of along-track error (latitude for a polar orbit) is difficult, and 2) for overhead passes the determination of the cross-track error (longitude for a polar satellite) is difficult since the slant range changes very little for changes in cross-track position when near the plane of the satellite orbit.

In an absolute sense, Fig. 1 does not represent the ultimate accuracy if all possible data points are used, transmitter power is increased to its practical limit, and more sophisticated curve fitting techniques are used. For order-of-magnitude calculations, a useful approximation is the following: if the RMS frequency error for each independent data point is σ_f, and the number of data points is N, the errors given in Fig. 1 can be scaled by $\sqrt{47/N}\cdot\sigma_f/0.5$. For example, assume the ultimate to be about one independent data point per second, and the RMS noise level to be 0.05 cps. At a 500-nautical mile ground range with a 400-mile satellite, the pass lasts for approximately 12 minutes or about 700 data points are received. Using, from Fig. 1, a navigational error of 0.1 nautical mile for 47 data points and 0.5-cps noise level, a true ultimate accuracy could be stated to be of the order of $0.1\sqrt{47/700}\cdot 0.05/0.5 = 0.003$ nautical mile$\cong$20 feet. Clearly, this number is only of academic interest because, without going to extreme complexity of instrumentation and computing techniques to eliminate the obvious errors due to nonstatistical biases, the statistical errors will contribute negligible error to the total navigation error. Applications such as those described by R. R. Newton in this issue justify the extreme care necessary to make the system as accurate as possible.

In summary, it can be seen that, for all practical purposes, statistical errors will not contribute a significant error to satellite Doppler navigation (except at the two extremes in ground range) when the system is economically designed to yield navigation accuracies of 0.5 nautical mile accuracy. Several possible sources of nonstatistical or biasing errors will now be considered.

B. Errors Contributed by Nonstatistical Biases

From the foregoing discussion, it can be seen that the inherent error in the system is well below one-half mile if careful accounting is made of all nonrandom sources of error. Several such sources of error are considered that are nonstatistical in nature.

1) *Ionospheric Refraction:* A major source of error in all satellite radio tracking schemes is ionospheric refraction. For purposes of studying its effect upon the Doppler shift, the ionosphere can be replaced by an equivalent index of refraction.[1,8] Since the Doppler shift of the satellite signal is basically the time rate of change of its electromagnetic path length, the Doppler shift is altered from what it would be in the absence of the ionosphere.

In the Appendix the equations for the Doppler shift in the presence of the ionosphere are given where the ionospheric contributions are stated in terms of a power series in the inverse of the transmitter frequency f.

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[8] J. A. Stratton, "Electromagnetic Theory," McGraw-Hill Book Co., Inc., New York, N. Y., p. 327; 1941.

Above 200 mc, the first term of the power series is usually all that is important. Using the mathematical expression for the first term that is given in the Appendix, the ionospheric contribution to the Doppler shift can be calculated and a typical result is shown in Fig. 2. The contribution shown in Fig. 2 was based upon the assumption that the electron density is only a function of altitude with a maximum density of 10^6 electrons per cubic centimeter at an altitude of 50 nautical miles.

The navigational error produced by ionospheric refraction can be understood qualitatively by noting that the maximum slope of the Doppler curve is a rough measure of the slant range, and that refraction has a direct effect upon this slope. Since the effect of refraction is to decrease the slope, the refraction error will be such as to place the navigator further from the satellite subtrack than would be true if the ionosphere were absent. To illustrate, a computation was performed similar to the calculations described in Section III-A. A synthetic Doppler curve was computed as before, but a refraction contribution was introduced in addition to the random errors simulating noise. The position of the navigator was then determined assuming that this refracted synthetic Doppler curve was a true experimental curve which contained no refraction. The results indicated that at a ground range of 500 nautical miles and a transmitter frequency of 200 mc, the navigational error was approximately 2 nautical miles. Furthermore, it was found that the best attainable fit of the refracted synthetic Doppler curve by the unrefracted theoretical Doppler curve was about 2 cps RMS, as opposed to a fit of about 0.2 cps RMS when the refraction contribution was not included.

Studies on the effects of refraction such as above indicated that the refraction contributions could not be ignored for transmitter frequencies as high as 500 mc. Furthermore, a cursory glance at the degree to which the electron distribution in the ionosphere could be predicted, so as to make an *a priori* correction for refraction, indicated that such predictions were not sufficiently reliable to reduce the refraction errors dependably below one-half mile.[9] Since it was felt that it was inadvisable to use satellite transmitter frequencies of the order of 1000 mc for the navigation system, studies were made to determine the degree to which the ionospheric effects could be eliminated experimentally by the use of two transmitter frequencies and thereby take advantage of the dispersive effect of the ionosphere.

From the Appendix, it can be seen that the Doppler shift in the presence of the ionosphere is of the form

$$\Delta f(f \mid t) = -\frac{f}{c}\dot{\rho}(t) + \frac{\alpha(t)}{f} + \frac{\beta(t)}{f^2} + \cdots. \qquad (1)$$

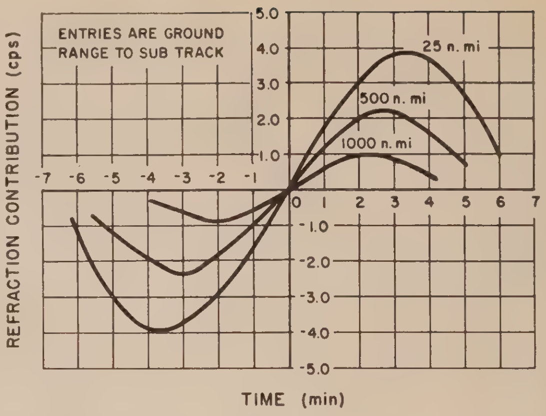

Fig. 2—Refraction contribution to Doppler shift, as a function of time, for several values of ground range. Transmitter frequency is 200 mc.

Noting that this form is true at each instant of time, it is clear that simultaneously measuring the Doppler shift at two different frequencies affords sufficient data to eliminate the first order refraction term, so that the result yields the vacuum Doppler shift plus only second order contributions of refraction. Eq. (2) indicates the trivial algebra necessary to eliminate the first order refraction contribution, and, of course, could be done in real time by frequency multipliers and a mixer provided f_1 and f_2 are harmonically related.

$$\Delta f_1(f_1 \mid t) = -\frac{f_1}{c}\dot{\rho} + \frac{\alpha}{f_1} + 0\left(\frac{1}{f_1^2}\right)$$

$$\Delta f_2(f_2 \mid t) = -\frac{f_2}{c}\dot{\rho} + \frac{\alpha}{f_2} + 0\left(\frac{1}{f_2^2}\right)$$

$$(f_2\Delta f_2 - f_1\Delta f_1) = -(f_2^2 - f_1^2)\frac{\dot{\rho}}{c} + 0\left(\frac{1}{f_{1,2}}\right). \qquad (2)$$

In these equations, $\dot{\rho}(t)$ is the time rate of change of the slant range from navigator to satellite as a function of time and contains all the information that is contained in the vacuum Doppler shift.

From the above discussion it can be seen that the effects due to refraction can contribute navigational errors only in second order when two frequencies are used, for example, 200 mc and 400 mc, and, consequently, a large step is made towards eliminating the ionosphere as a source of error. Table II gives an estimate of the relative magnitudes of refraction contributions as a function of frequency, and it can be seen that, based upon these data, two frequencies above 200 mc should be adequate to reduce the errors due to refraction to below 0.5 mile, remembering that the first order effect at 200 mc produced an error of about 2 miles.

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[9] E. L. Crow and D. H. Zacharisen, "Pilot Study of the Preparation of World Maps of F_2 Critical Frequencies and Maximum Usable Frequency Factors," National Bureau of Standards, Boulder, Colo.; NBS Rept. 5560; February 28, 1958.

In estimating the quantities appearing in Table II, no attempt was made to include effects such as winds and turbulence that can occur in the ionosphere, nor to include extremes that can occur at rare times during magnetic storms, etc. Consequently, there is still some question as to how small the residual refraction effects are under some circumstances. Nevertheless, it appears at the present time that for the large majority of cases the use of two frequencies can sufficiently eliminate the errors due to ionospheric refraction to below one-half mile.

TABLE II

Refraction Contributions to the Doppler Shift

f (mc)	Vacuum term* (cps)	First order term* (cps)	Second order term* (cps)
50	1,250	10	0.5
100	2,500	5	0.08
200	5,000	2.5	0.01
500	12,500	1.0	—

* These are typical maxima of these quantities for a given Doppler curve and do not necessarily occur at the same time.

2) *Frequency and Frequency Drift Error:* Studies were made on the navigational error produced by instabilities in the frequency of the satellite transmitters and/or the navigator's local oscillator. First, it was found that when an unknown but constant frequency error occurred, no significant navigational error resulted so long as the navigator's position was computed by allowing the frequency of the satellite (more properly, the beat frequency between the satellite's transmitter and the navigator's local oscillator) to be an adjustable parameter, so that the navigational fix was determined by a three parameter fit to the experimental Doppler curve instead of a two parameter fit.

The fact that a three parameter fit produces no significant increase in navigational error over and above a two parameter fit, even when no frequency error exists, is due principally to the fact that the entire Doppler curve is used. When the entire curve is used, the shapes of the changes in the Doppler shift as a function of time that result from changes in frequency, latitude, and longitude, are completely different and, therefore, frequency, latitude, and longitude are "orthogonal" parameters. Consequently, the use of the whole of the Doppler curve not only provides redundant statistics for increasing the navigational accuracy, but also eliminates the error due to an unknown but constant frequency error. Because absolute accuracy of the various oscillators in the system would be expensive to achieve and maintain in practice, it was decided very early that a three parameter navigation calculation would always be necessary. Consequently, in all error analyses, including those quoted above, a three parameter calculation was made.

If either the satellite transmitters or the navigator's local oscillator change in frequency significantly during the pass of the satellite, the resulting navigation error is not so easily eliminated. Table III indicates the error that results from various drift rates of the oscillators, and again these figures were arrived at by simulating navigation (three parameter fit) using synthetic experimental data as outlined for previous calculations.

From Table III it can be seen that a stability of one part in 10^8 per hour is sufficient to allow navigation to one-half mile accuracy. Since such stabilities are not difficult to attain, no further attempt was made to study ways of reducing the errors by, for example, progressing to a four parameter fit.

TABLE III

Navigation Error Arising from Frequency Drift
Ground Range = 400 Nautical Miles

Drift Rate (parts in 10^8/hr.)	Latitude Error (nautical miles)	Longitude Error (nautical miles)	Total Error (nautical miles)
0	0.08	0.1	0.13
1	0.12	0.19	0.23
10	0.15	0.80	0.86
50	1.13	2.86	3.08

3) *Error in the Navigator's Velocity:* An obvious source of error, which is of a nonstatistical nature, is an error in the navigator's velocity which, in effect, is an input to the computation of position. This error does not appear to be serious, however, unless special applications such as aircraft navigation are contemplated. It seems probable that a ship, for which accurate navigation to one-half mile is important, would know its velocity relative to the Earth to within one or two knots. Since the relative motion of the ship is only important during the pass time of the satellite (10 to 15 minutes), this means that the error in the position relative to ϕ_0 and λ_0 should be less than 0.5 nautical mile. Furthermore, as was the case for an unknown frequency, the alteration of the Doppler shift due to a velocity error of the navigator has a shape with time that is somewhat different than that caused by change of the parameters ϕ_0 and λ_0. Consequently, velocity errors produce changes in the Doppler curve that are partially orthogonal to the navigator's position. Therefore, the full effect of the velocity error is not felt in the navigational error. Typical navigational errors appear to be about one-half to two-thirds of the total error accrued in the ship's position during the pass time of the satellite, and, consequently, a two-knot velocity error produces about a one-fourth to one-third nautical mile navigational error.

Another possibility obviously exists for those ships for which accurate navigation is crucial. A crude autopilot could be used to measure velocity during the time that the satellite is above the horizon, and thereby reduce velocity errors to a negligible factor.

4) *Miscellaneous Sources of Error:* There are many sources of error that have not yet been mentioned. Such errors as uncertainty in the altitude of the navigator,

errors introduced by multipath reception of the signal (*e.g.*, reflection of the signal from the satellite by the water when the satellite is low on the horizon), the existence of more than one solution for the navigator's position, and many others, have been considered and do not appear to be serious. However, in studying them, several interesting facts have emerged which are worth mentioning.

First, altitude errors do not appear serious, since, for surface navigation, altitude (particularly at sea) is known to much better than a tenth of a mile. Such small errors make a negligible contribution. Signal propagation errors such as multiple path reception can be eliminated by building antennas that have nulls at the horizon, or by discarding data from the beginning and end of a pass. The amount of Doppler data lost by not receiving the signal below a few degrees elevation is not serious since, as emphasized previously, so many data points are received that the loss of these data are of little consequence.

Many sources of error that are significant to other types of navigation are not pertinent here. For example, since no angle measurements are involved, stabilizing of antennas is not required. Furthermore, no knowledge of the local vertical is needed, nor is a knowledge of true north.

Finally, an interesting point arises when considering the possibility that more than one position of the navigator yields the same fit of the experimental data. It was found that if the navigator was so ignorant of his approximate position that an attempt was made to find a position on the wrong side of the satellite subtrack, a minimum in the mean square fit of the Doppler data with respect to frequency, latitude, and longitude could be found. However, for this false minimum, the fit of the data was very poor as compared to the fit obtained on the correct side of the satellite subtrack. This poor fit arises because the rotation of the Earth gives the navigator an extra component of velocity relative to the satellite that changes sign when going from one side of the satellite subtrack to the other side. Consequently, if the navigator should find the false fit to the data, indicated by large residuals between the theoretical Doppler curve and the experimental data, the true position can be found by shifting to the other side of the satellite subtrack. To this date, no other false solutions have been found.

IV. CONCLUSIONS

It has been shown that when full use is made of the Doppler data, satellite Doppler navigation to an accuracy of one-half nautical mile is theoretically feasible. The necessary satellite instrumentation is attainable in the present state of the art. The satellites should contain two transmitters at different frequencies, say 200 and 400 mc, and should have a stability of about one part in 10^8 and power levels of about 100 mw. To supply the necessary inputs conveniently to the navigator and allow for updating the satellite orbits frequently, the satellites should contain a digital memory with means for receiving orbital data and time corrections from an injection station, and a means for serially reading out the memory and modulating at least one of the transmitters with these data together with a time synchronizing signal obtained from the satellite's oscillator. This allows the navigator to receive the time pulse with its correction and the orbital data necessary to perform the calculation of position. A system of three to four satellites in the proper orbits allows a navigation fix at least once every two hours.

It has been indicated that the main contributors to the navigational error are the various sources of biases, and not the fundamental experimental noise. Use of the whole Doppler curve, furthermore, allows for a three-parameter fit of the experimental vacuum Doppler data, the latitude and longitude of the navigator, and a vernier correction to the frequency. The use of a three-parameter fit makes it unnecessary to hold absolute accuracy of the satellite and navigator's oscillators. The second-order refraction effects that remain when two frequencies are used may be the major source of error, particularly in special circumstances when magnetic storms are present or when navigating in the auroral regions. However, for typical ionospheric conditions, the use of two frequencies to eliminate first order refraction effects is sufficient to allow one-half mile accuracy.

Navigation by such a satellite Doppler system has many obvious advantages. The system is all weather, passive, and accurate. The navigator does not need to have knowledge of local vertical or the direction of north. Since no angle data are needed, special antenna arrays are not needed nor do the problems of antenna bore-sighting or stabilization arise. Depending upon the navigational accuracy required, the navigator can employ various degrees of sophistication in his instrumentation and computing equipment.

In conclusion, one further remark is worth mentioning. Assuming the existence of a reliable world-wide navigation system which has an accuracy of one-half mile, its optimum use is mapped to at least this accuracy. As discussed in another paper in this issue, a more careful application of the same principles would provide the means for such accurate mapping of the world.

APPENDIX

EQUATIONS FOR THE DOPPLER SHIFT IN THE PRESENCE OF THE EARTH'S IONOSPHERE

This Appendix presents the derivation of the Doppler shift (including first-order refraction effects) as a function of the geodetic position of the navigator, the time, the satellite frequency, and the ionospheric electron density. The notation used is discussed, the major assumptions necessary for the derivation are listed, a derivation is given of the first two terms in the series expansion of the refracted Doppler shift in powers of one over the transmitter frequency, and finally, the detailed expressions for the vacuum Doppler shift are given.

A. Notation

t = time

$x_s(t), y_s(t), z_s(t)$ = Cartesian coordinates of the satellite in a right-handed system where the origin is at the earth's *CG*, the x-z plane coincides with the Greenwich meridian, and the x-y plane coincides with the earth's equatorial plane

$\phi(t)$ = geodetic latitude of the navigator

$\lambda(t)$ = geodetic longitude of the navigator

ϕ_0, λ_0 = geodetic latitude and longitude of the navigator at a time t_0, chosen to be some time during the pass of the satellite

a, f_0 = semimajor axis and flattening of navigator's datum

$x_n(t), y_n(t), z_n(t)$ = Cartesian coordinates of the navigator in the above coordinate system

$\rho(t)$ = instantaneous slant range between the navigator and satellite

$N(x, y, z)$ = electron density in the ionosphere per cubic centimeter

e = electronic charge in esu

m = electron mass in gm

$f_N(x, y, z)$ = ionospheric plasma frequency $= \sqrt{N(x, y, z)e^2/\pi m}$

$n(x, y, z|f)$ = equivalent refractive index of ionosphere

f = satellite transmitter frequency

c = velocity of light in vacuum

$P(t)$ = optical path of CW signal from satellite to navigator

$Pg(t)$ = geometric path of CW signal from satellite to navigator

ds = differential arc length along some defined path P

$0(\xi)$ = terms of order ξ or higher

$\dot{g}(t)$ = time derivative of $g(t)$

$\Delta f(f|t) = \Delta f(\lambda_0, \phi_0, f|t)$ = refracted Doppler shift.

B. Assumptions

1) The satellite transmitter frequencies are above 100 mc.
2) The effects of the ionosphere can be described to a sufficient approximation for $f \geq 100$ mc by ascribing to the ionosphere an equivalent index of refraction given by

$$n(x, y, z) = \sqrt{1 - \left[\frac{f_N(x, y, z)}{f}\right]^2},$$

and the phase velocity of the signals transmitted from the satellite is given by $v = c/n(x, y, z)$.

3) The change in altitude of the navigator during the pass of the satellite is negligible, *i.e.*, surface navigation is assumed.
4) Relativistic effects are negligible.

C. Refracted Doppler Shift Represented as a Power Series in 1/f

Using the above assumptions, when both transmitter and receiver are moving slowly compared to the speed of light, the Doppler shift is given by

$$\Delta f(f|t) = -\frac{f}{c}\frac{d}{dt}\int_{P(t)} n(x, y, z|f)ds(x, y, z), \tag{3}$$

where the optical path $P(t)$ is defined as that path for which

$$\int_{P(t)} n(x, y, z|f)ds(x, y, z)$$

is an extremum in comparison with all possible paths that begin at the satellite and end at the receiver. Consequently

$$\int_{P(t)+\delta P(t)} nds - \int_{P(t)} nds = 0(\delta P^2), \tag{4}$$

where $\delta P(t)$ is any path that lies close to $P(t)$.

To start the development of the Doppler shift, $\Delta f(f|t)$, in a power series in $1/f$, (4) can be applied by identifying $\delta P(t)$ with the small difference in the optical and geometric paths when $f \geq 100$ mc. Noting first that

$$\lim_{1/f \to 0} n(f) = 1 \quad \text{and} \quad \lim_{1/f \to 0} P(t) = Pg(t),$$

it is reasonable to suppose that $\delta P(t) = P(t) - Pg(t) = 0(1-n)$. Thus, when the refractive index n lies close to unity, as it does when $f \geq 100$ mc, (4) becomes

$$\int_{P(t)} n(x, y, z|f)ds(x, y, z) = \int_{Pg(t)} n(x, y, z|f)ds(x, y, z) + 0[(1-n)^2].$$

Rewriting the above equation,

$$\begin{aligned}\int_{P(t)} n(x, y, z|f)ds(x, y, z) &= \int_{Pg(t)} ds(x, y, z) - \int_{Pg(t)} [1 - n(x, y, z|f)]ds(x, y, z) \\ &\quad + [0(1-n)^2] \\ &= \rho(t) - \int_{Pg(t)} (1-n)ds + 0[(1-n)^2],\end{aligned} \tag{5}$$

where $\rho(t)$ is the geometric slant range from navigator to satellite, and is independent of $n(x, y, z|f)$.

Again, noting that for $f \geq 100$ mc,

$$\frac{f_N(x, y, z)}{f} \ll 1,$$

and

$$1 - n(x, y, z \mid f) = \frac{1}{2}\left(\frac{f_N}{f}\right)^2 + 0\left[\left(\frac{f_N}{f}\right)^4\right].$$

Thus,

$$\begin{aligned}\int_{P(t)} n(x, y, z \mid f) ds(x, y, z) \\ = \rho(t) - \frac{1}{2f^2}\int_{P_g(t)} f_N{}^2 ds(x, y, z) + 0\left[\left(\frac{f_N}{f}\right)^4\right].\end{aligned} \quad (6)$$

Substituting (6) into (3) yields the required power series to first order.[10]

$$\begin{aligned}\Delta f(f \mid t) = -\frac{f}{c}\dot{\rho}(t) + \frac{1}{2fc}\int_{P_g(t)} f_N{}^2(x, y, z) ds(x, y, z) \\ + 0\left(\frac{f_N{}^4}{f^3}\right).\end{aligned} \quad (7)$$

D. Dependence of the Vacuum Doppler Shift on the Position of the Navigator

It was established in Section III that it is sufficient to define the navigator's position to be the value of the geodetic latitude and longitude of the navigator at some instant of time t_0 that occurs approximately in the middle of the pass of the satellite.[11] Let this position be denoted by

$$\left.\begin{aligned} \phi_0 &= \phi(t_0), \\ \lambda_0 &= \lambda(t_0), \\ &\text{and let} \\ \delta\phi(t) &= \phi(t) - \phi(t_0), \qquad \dot{\phi}(t) = \delta\dot{\phi}(t), \\ \delta\lambda(t) &= \lambda(t) - \lambda(t_0), \qquad \dot{\lambda}(t) = \delta\dot{\lambda}(t). \end{aligned}\right\} \quad (8)$$

Then, under the above assumptions, to a sufficient approximation,

$$\left.\begin{aligned} \zeta_n(\phi_0) &= \frac{a}{\sqrt{\cos^2 \phi_0 + (1 - f_D)^2 \sin^2 \phi_0}} \\ \xi_n(\phi_0 \mid t) &= \zeta_n(\phi_0) \cos \phi(t) \\ \dot{\xi}_n(\phi_0 \mid t) &= -\left[\zeta_n(\phi_0) \sin \phi(t)\right]\dot{\phi}(t) \end{aligned}\right\} \quad (9)$$

$$\left.\begin{aligned} x_n(\phi_0, \lambda_0 \mid t) &= \xi_n(\phi_0 \mid t) \cos \lambda(t) \\ \dot{x}_n(\phi_0, \lambda_0 \mid t) &= \dot{\xi}_n(\phi_0 \mid t) \cos \lambda(t) - y_n(t)\dot{\lambda}(t) \\ y_n(\phi_0, \lambda_0 \mid t) &= \xi_n(\phi_0 \mid t) \sin \lambda(t) \\ \dot{y}_n(\phi_0, \lambda_0 \mid t) &= \dot{\xi}_n(\phi_0 \mid t) \sin \lambda(t) + x_n(t)\dot{\lambda}(t) \\ z_n(\phi_0 \mid t) &= \zeta_n(\phi_0)(1 - f_D)^2 \sin \phi(t) \\ \dot{z}_n(\phi_0 \mid t) &= \xi_n(\phi_0 \mid t)(1 - f_D)^2 \dot{\phi}(t). \end{aligned}\right\} \quad (10)$$

Using the above equations, the Doppler shift is given by

$$\begin{aligned} \rho(\phi_0, \lambda_0 \mid t) &= \left\{\left[x_s(t) - x_n(t)\right]^2 + \left[y_s(t) - y_n(t)\right]^2 + \left[z_s(t) - z_n(t)\right]^2\right\}^{1/2} \\ \dot{\rho}(\phi_0, \lambda_0 \mid t) &= \frac{(x_s - x_n)(\dot{x}_s - \dot{x}_n) + (y_s - y_n)(\dot{y}_s - \dot{y}_n) + (z_s - z_n)(\dot{z}_s - \dot{z}_n)}{\rho(\phi_0, \lambda_0 \mid t)}. \end{aligned} \quad (11)$$

From (7) it can be seen that the zeroth order term is the vacuum Doppler shift and the first order term is a correction to the vacuum Doppler shift due to the presence of the ionosphere. Noting that the plasma resonance frequency f_N is proportional to the square root of the electron density, it can be seen that (7) exhibits the well-known fact that, to a good approximation, the refraction contribution to the Doppler shift is proportional to the time rate of change of the total number of electrons along the signal path.

Substituting (11) into the expression for the vacuum Doppler shift, $-f\dot{\rho}(\phi_0, \lambda_0 | t)/c$, yields the required dependence of the Doppler shift on the geodetic position of the navigator.

ACKNOWLEDGMENT

The authors acknowledge the contributions of F. T. McClure, who originally suggested the application to navigation, and R. B. Kershner, who, with Mr. McClure, made most of the contributions to the concepts of the over-all system. R. R. Newton and many others at the Applied Physics Laboratory, Johns Hopkins University, also contributed to many stimulating discussions.

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[10] The above power series has been rigorously proved by one of the authors (W. H. Guier) to be correct to third order under the above assumptions and proved to first order when the second assumption has been removed. There appears no reason to believe that such a representation of the refracted Doppler shift to higher order is not valid.

[11] Clearly, for aircraft navigation, this definition must be generalized to be useful. While introducing no essential complications in theory, such considerations are beyond the scope of this paper.

Electrically-Controlled Demand-Thrust Rockets for Satellite Guidance*

DOUGLAS D. ORDAHL†

Summary—**Satellites which can be positioned precisely in space will be required for the space research programs of the near future. The information obtainable with such vehicles will be of immediate importance to both military and basic scientific research programs. Typical applications include meteorological observations, communications, atmospheric research and, ultimately, soft-landing vehicles for manned space travel. To accomplish accurate control of orbit and/or attitude with rocket motors requires extremely precise regulation of thrusts, generally in the range between 0 to 1 or 0 to 10 pounds. It must be possible to turn these control forces on and off in a few milliseconds repeatedly or intermittently over periods of from several months to perhaps several years. For use in such applications, rocket units have been investigated which employ the combination of storable-liquid propellants and demand-thrust injectors capable of complete remote control. An experimental model of a 0- to 10-pound thrust engine has been successfully demonstrated. Three types of electrically actuated control systems are being investigated. These systems employ direct solenoid control, a magnetic ram hydraulic booster, and a micropump with a hydraulic servomechanism. Guidance signals of 50 microamps are used to regulate power to the engine controls.**

INTRODUCTION

ATTAINMENT of the objectives of both the scientific and military space programs requires use of a rather large number of satellites and space vehicles which can be guided over relatively long periods of time after the main propulsion engines have separated or shut down. The applications include satellites for meteorological observations, communication relays, probes for atmospheric research, soft-landing vehicles for moon and planetary probes, and, ultimately, manned space travel. The types of guidance problems encountered include, 1) the relatively simple task of correcting elliptical orbits into the more stable circular paths, 2) the more sophisticated establishment of a preselected orbit, and 3) the very precise task of positioning a satellite with respect to orbital shape, direction, elevation, and attitude for observation of specific points on earth or areas in space.

Because of the well-publicized weightless, frictionless conditions which prevail, satellite or space vehicle guidance must be accomplished by the application of reaction forces including cases where such devices as gyro stablization may be used. In contrast to the extremely large thrust required to place a vehicle in orbit, the forces required for even relatively major corrections to vehicles weighing as much as 1000 pounds are only in the region of 10 pounds thrust. In addition, extremely precise control is required over the thrust level and action time to prevent errors of over-correction. Interpreting these problems in terms of the specific requirements that must be provided by the rocket system shows that 1) the response times in reaching thrust level must be no longer than 10 milliseconds, 2) the propulsive force must be delivered either in extremely reproducible short impulses or must respond rapidly and accurately to the demand for any required thrust level within the capacity of the engine, and 3) the system must be completely storable and capable of intermittent response for periods of as much as one year or more. In addition to these requirements the highest effective impulses available are required to maintain the weight and volume of the satellite vehicle at the practical minimum.

DEVELOPMENT OF DEMAND-THRUST ENGINES USING STORABLE LIQUID PROPELLANTS

In the past two years, research on variable-thrust storable-liquid propellant propulsion systems (undertaken originally in connection with advanced air-to-air missile work) resulted in the development of a simple engine which could be turned completely on or off or adjusted to any desired thrust level on demand. This development used storable hypergolic liquid propellants, pressure pumped to a variable area injector which maintains proper balance in the flow of an oxidizer and fuel at all thrust levels. Most of the work has been carried out using such propellants as unsymmetrical dimethylhydrazine and red fuming nitric acid; however, a rather wide variety of propellant combinations can be used successfully providing they are hypergolic with short ignition delays. Nonhypergolic propellant combinations could be used with the provision of an adequate ignition system. An example of the reliability and durability of the design is indicated by the typical experience with one 3500-pound thrust engine having an accumulated test time of over six hours with no signs of deterioration.

As the requirements for satellite and space vehicle guidance became known, the concept of the storable demand-thrust engine was extended to include a series of very small engines such as the 0- to 10-pound motor shown in Figs. 1 and 2. This particular engine weighs less than one pound and operates at a combustion chamber pressure of 200 psi. A series of test firings in the static test stand shown in Fig. 2 has demonstrated instantaneous ignition, smooth combustion, complete shut-off on demand without leakage, and no evidence

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* Original manuscript received by the IRE, November 23, 1959.
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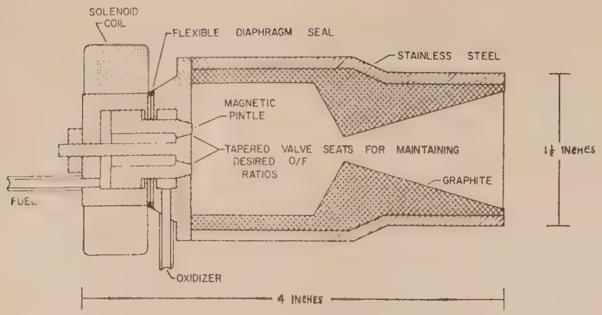

Fig. 1—Zero- to 10-pound variable thrust engine.

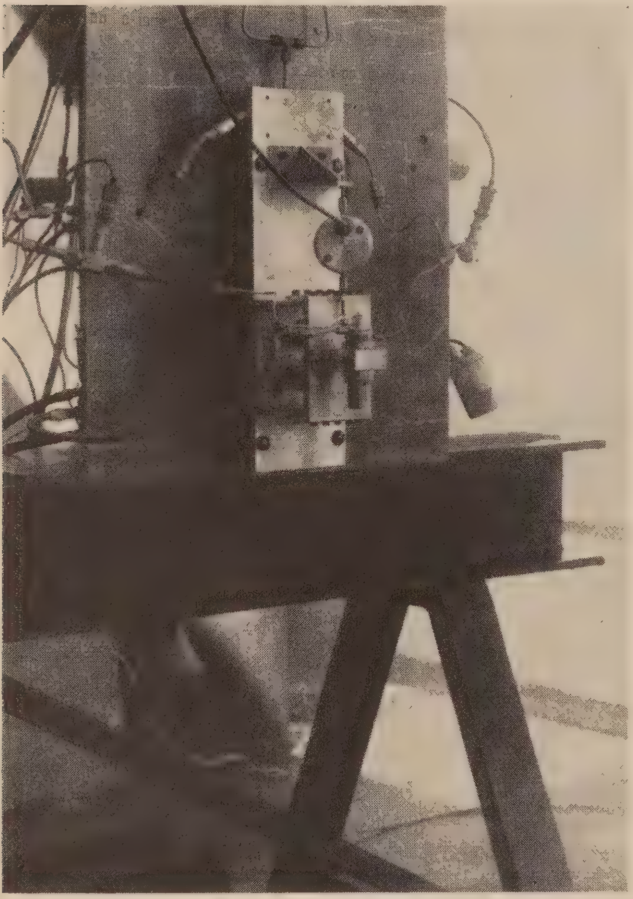

Fig. 2—Zero- to 10-pound variable thrust motor operating in the static test stand. Flame is colorless.

of deterioration after an extended period of operation. Response times with suitable electrical power are estimated to be less than 10 milliseconds. An interesting discovery is that in all the tests made the flame has been completely colorless except during start-up and shut-down. The motor shown in Fig. 2 is actually operating at full thrust.

Control Methods for Integrated Systems

An optimum design for a 0- to 10-pound demand-thrust engine is estimated to require no more than 0.1 watt of power for the electrical controls. However, the familiar problems of weight, size, and response optimization are encountered and proper selection of a control circuit depends to a significant degree on the particular application. Where suitable electrical power is available, direct solenoid actuation is a reasonable choice to achieve high rates of response. On the other hand, systems may be required which use hydraulic pressure or other forms of control to minimize power consumption.

With these considerations in mind, several other methods are under development for actuation of the demand-thrust motors. It should be noted at this point that some navigation systems will require linear thrust level control, particularly where closed-loop servos are employed, and some systems will require predetermined impulses to be delivered in a square wave pattern. In the system diagram shown in Fig. 3, pressurization of the liquid propellants is accomplished by a helium gas bottle, and, as the fluids are expelled, thin metal bags collapse to prevent sloshing, much as in a toothpaste tube. An amplifier and a secondary power supply are used to build up the control signal sufficiently to operate the solenoid coil at the desired rate of response. A typical power supply for this application would comprise a 12-volt nickel-cadmium battery weighing 0.75 pound and a solar cell recharge system which would weigh as much as 4 pounds. The magnetic amplifier would be of the 2- or 3-stage transistor type weighing 0.5 pound and furnishing 2 watts to the solenoid coil controlled by an input signal of 50 microamps. The solenoid coil used requires 1.5 watts for operation and weighs 0.25 pound.

The diagram shown in Fig. 4 illustrates the use of an electrohydraulic actuator for driving the injector. This design would use hydraulic pressure on an enlarged area on the base to move the injector pintle. The electrical power would drive the solenoid actuated piston to increase or decrease the hydraulic pressure as required. This pressure would oppose the fuel pressure acting to close the piston. Thus, as the position of the small solenoid or magnetic piston is retracted, the pressure drops and the pintle closes, reducing or stopping the thrust.

The system illustrated in Fig. 5 makes use of hydraulic control of the injector obtaining the hydraulic pressure from a micropump. Use of this system presumes that sufficient electrical power would be available from other components in the vehicle to operate the pump. The electrically actuated servo valve would be one of a type currently available and would require only 10 milliwatts from the guidance systems for control. The micropump used in this design requires a power input of 50 watts and produces a flow rate up to 0.025 gallon per minute at 1000 psi.

Typical Applications

Among the typical applications that have been studied for small demand-thrust motors, is the type of vehicle shown in Fig. 6. Such a vehicle will use 12 small

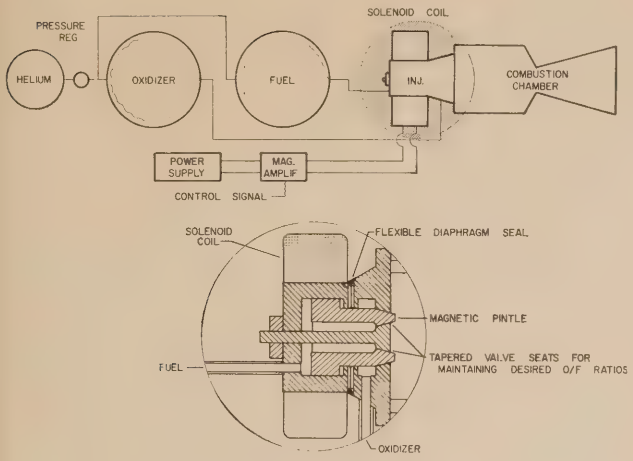
PRESSURE REG
HELIUM
OXIDIZER
FUEL
SOLENOID COIL
INJ.
COMBUSTION CHAMBER
POWER SUPPLY
MAG. AMPLIF.
CONTROL SIGNAL
SOLENOID COIL
FLEXIBLE DIAPHRAGM SEAL
MAGNETIC PINTLE
TAPERED VALVE SEATS FOR MAINTAINING DESIRED O/F RATIOS
FUEL
OXIDIZER

Fig. 3—Zero- to 10-pound variable thrust propulsion system with direct electrical actuation.

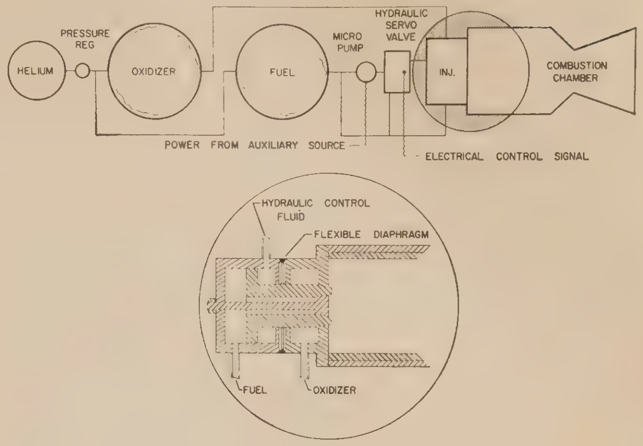
PRESSURE REG
HELIUM
OXIDIZER
FUEL
MICRO PUMP
HYDRAULIC SERVO VALVE
INJ.
COMBUSTION CHAMBER
POWER FROM AUXILIARY SOURCE
ELECTRICAL CONTROL SIGNAL
HYDRAULIC CONTROL FLUID
FLEXIBLE DIAPHRAGM
FUEL
OXIDIZER

Fig. 5—Zero- to 10-pound variable thrust propulsion system with hydraulic servo controls.

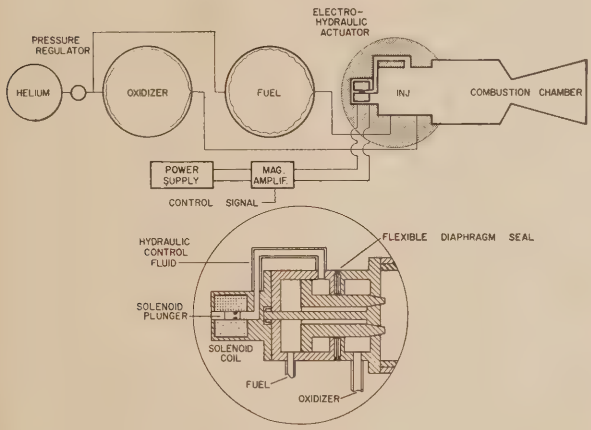
PRESSURE REGULATOR
ELECTRO-HYDRAULIC ACTUATOR
HELIUM
OXIDIZER
FUEL
INJ
COMBUSTION CHAMBER
POWER SUPPLY
MAG. AMPLIF.
CONTROL SIGNAL
HYDRAULIC CONTROL FLUID
FLEXIBLE DIAPHRAGM SEAL
SOLENOID PLUNGER
SOLENOID COIL
FUEL
OXIDIZER

Fig. 4—Zero- to 10-pound variable thrust propulsion system with electrohydraulic actuation.

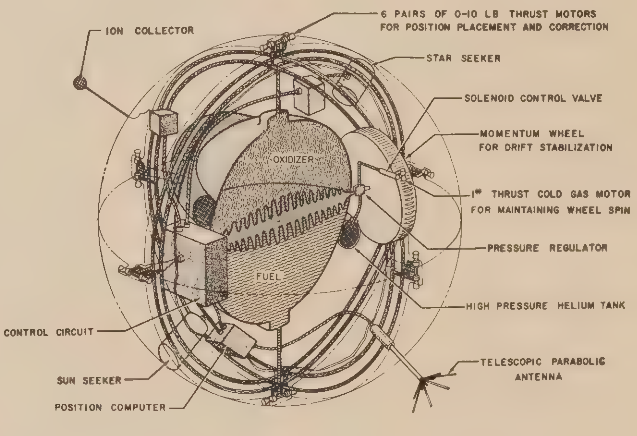
ION COLLECTOR
6 PAIRS OF 0-10 LB THRUST MOTORS FOR POSITION PLACEMENT AND CORRECTION
STAR SEEKER
SOLENOID CONTROL VALVE
MOMENTUM WHEEL FOR DRIFT STABILIZATION
1# THRUST COLD GAS MOTOR FOR MAINTAINING WHEEL SPIN
PRESSURE REGULATOR
HIGH PRESSURE HELIUM TANK
OXIDIZER
FUEL
CONTROL CIRCUIT
SUN SEEKER
POSITION COMPUTER
TELESCOPIC PARABOLIC ANTENNA

Fig. 6—Typical research satellite using six pairs of opposed demand thrust jet motors for position control.

engines for position or short term attitude control. A typical application is for a 22,300-mile or 24-hour orbit civil communications satellite to maintain a fixed position. To permit the use of a parabolic antenna for minimizing transmitter output, such a satellite would need to be at least approximately oriented toward appropriate ground receivers. Other possible applications for vehicles such as the one illustrated are for earth and space scanning devices and scientific satellites which can be programmed into several different orbits.

Somewhat larger electrically controlled demand thrust engines (in the range of 5000 to 10,000 pounds thrust) would satisfy the requirements for a soft-landing vehicle to place an instrumented payload on the moon and would ultimately be useful in bringing one or more satellites together at a point in space. Such vehicles which can maneuver effectively in space would require a main lift (or retarding) motor and several smaller units for attitude control. Demonstration vehicles have been designed which could be electrically or radio controlled from the ground in flights as high as 50,000 feet from the earth. These vehicles could be used primarily to carry out experimental investigations on the integration of control, actuation, and propulsion systems. The variable-thrust propulsion units required for this type of experimental vehicle have already been designed and tested. In addition, the operation of injectors for engines of 0- to 20,000-thrust capacity have been demonstrated successfully.

A final application of immediate interest to the missile and space vehicle designer is that the small demand thrust motor shown in Fig. 1 uses so little propellant that it is suitable for a number of detailed high altitude studies of motor and propellant performance using relatively inexpensive vacuum chambers to get much of the data which was heretofore possible only from large elaborate installations. This unit is being used to investigate advanced designs for electrically actuated control systems and propellant performance characteristics at simulated altitudes up to 250,000 feet.

Inertial-Guidance Limitations Imposed by Fluctuation Phenomena in Gyroscopes*

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Summary—**Because of recent improvements, inertial guidance is becoming increasingly important to space and missile programs in connection with the navigation of mobile bases and the launching of vehicles. Gyroscopes are an important component of inertial systems. In order to see if much room remains for further improvement, the performance limitation imposed by thermal fluctuations in gyroscopes is examined. This is done because experience in electronics shows that thermal noise is the ultimate performance limitation in sensitive instruments such as radio receivers and galvanometers. It is found that a system limited only by thermal noise in its gyroscopes would have several orders of magnitude more precision than that indicated in published performance data. This must mean that other factors are limiting performance of gyroscopes, and investigation of several of these shows that bearing noise may be an important one. In conclusion, since gyroscopes do not yet come near to attaining the performance limits set by thermal noise, there may be much room left for their further improvement.**

INTRODUCTION

DURING the past decade, the concept of inertial guidance has been transformed from a vision in the minds of a few pioneering engineers and scientists to a practical reality that must be taken into account in the planning of all present and future space programs. The initial use of inertial guidance has been largely restricted to earth-bound vehicles in the form of aircraft, submarines, and, most recently, ballistic missiles. How large a role inertial systems of navigation will play in the space programs of the future, and the exact functions that may be performed by such systems, will be determined, in part, by the accuracies that can be obtained. Therefore, it is important to know how accurate such systems are likely to become as the result of further improvements in their basic components. This paper analyzes the performance limitations imposed on inertial-guidance systems through fluctuation phenomena in gyroscopes and their associated stable platforms—two basic and related elements in such systems.

An intertial guidance system is used to determine continuously the velocity and position of a vehicle relative to some external frame of reference but without the aid of information from external sources. Basically, this may be done by carrying in the vehicle a local reference frame that bears a known relationship to the external one. Vehicle accelerations measured in this local reference frame can be processed to obtain velocity and position information referred to the external coordinates. For example, if the two frames were sets of rectangular axes maintained parallel to each other and the external one was fixed in inertial space, then the velocity and position of the vehicle could be obtained by successive integrations of accelerations measured along the axes carried by the vehicle. However, because instruments for measuring acceleration are also sensitive to gravity, it is necessary to compensate for this factor. Furthermore, it is frequently desirable to navigate in terms of an external-coordinate system moving relative to inertial space. This is expecially true of earth-bound vehicles such as aircraft, submarines and missiles in which navigation is done relative to earth coordinates. Gravity and the need to navigate in moving coordinates are two factors which greatly complicate inertial navigation systems.

In order to provide an internal-coordinate system that bears a known relationship to the navigational (or external) coordinates, it is generally convenient to use some form of stable platform inside the vehicle. A stable platform isolates the internal reference frame from angular motion of the vehicle. The platform itself may act as a local reference frame and have accelerometers mounted directly on it, or it may be simply a stabilizer for a reference frame that exists numerically in a computer. In certain systems for aircraft and submarine navigation, the stable platform may be arranged to seek the local vertical; then, in effect, by comparing this vertical with the initial vertical, the angular displacement of the vehicle along its desired track around the earth can be determined. Motion perpendicular to this track can be determined from integration operations applied to a cross-track accelerometer signal.

The above is a brief description of the inertial-guidance concept. Because of the many possible configurations that guidance systems may take and because of the complexities of any practical system, this brief description will have to suffice for purposes of this paper. The interested reader may refer to the literature[1–3] for more details. The extent to which inertial-guidance concepts will be used in space flight is critically dependent upon the accuracy that can be achieved. With present accuracies, it is doubtful if inertial schemes could be used exclusively for the navigation of space-

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* Original manuscript received by the IRE, December 2, 1959.

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[1] C. F. O'Donnell, "Inertial navigation," *J. Franklin Inst.*, vol. 266, pp. 257–277, 373–401; October and November, 1958.

[2] J. M. Slater and D. B. Duncan, "Inertial navigation," *Aeronautical Engrg. Rev.*, vol. 15, pp. 49–52, 57; January, 1956.

[3] W. Wrigley, R. B. Woodbury, and J. Hovorka, "Inertial Guidance," Institute of Aeronautical Sciences, SMF Fund Paper No. FF-16 presented in January, 1957.

craft from one orbit to another. However, elements of such systems, *e.g.*, the stable platform, may be useful for isolating star-tracking devices from vehicle motion and for the other functions analogous to the autopilot of a conventional aircraft. For manned spacecraft it may be necessary to provide artifical gravity through vehicle rotation. Such rotation would necessitate a more elaborate type of autopilot than ordinary aircraft use, and some form of stable platform would be most useful.

PRECISION OF STABLE PLATFORMS

The heart of an inertial-guidance system is the stable platform which establishes the coordinate system for making acceleration measurements. Errors in the position of the stable platform would be directly reflected into errors in the computed position if the platform failed to maintain its prescribed position in relation to inertial space or the navigational coordinate system. Because of the key importance of the stable platform as a subsystem in an inertial navigator, an autopilot or a star-tracker, the remainder of this paper will be devoted exclusively to the question of platform positional accuracy.

The accuracy of a stable-platform system is largely determined by its *precision.* This situation results from the fact that great pains are taken to eliminate systematic errors through calibration procedures and through elaborate error compensation schemes. As the result of the care taken to eliminate systematic errors and as the result of the great improvement that has been made in the precision of the gyroscopes used to sense platform angular deviations, it has been possible to achieve accuracies in platforms that are satisfactory for many of the purposes for which they may be used in earth-bound vehicles. .

Consider one of the angular coordinates of a stable platform θ_p. Fig. 1 shows the characteristic behavior of an ensemble of platforms 1 through n. Although initially aligned so that the angles are zero at $t=0$, at some later time T_r, there is a distribution in platform positions. Assuming no systematic errors, the average position across the ensemble will, of course, be zero. However, any particular platform will deviate from the average position of zero in an unpredictable manner. The standard deviation σ_{θ_p} will be used in this paper to characterize the spread of platform positions about the mean value. This standard deviation will be found to contain an unbounded term which builds up as the square root of time. Attention will be focused on this term to the exclusion of all others, since for large values of T_r it will predominate. In practice, when the standard deviation of the platform position has grown to a maximum permissible level, it will be necessary to reset the platform back to zero by means of auxiliary equipment such as a star sight.

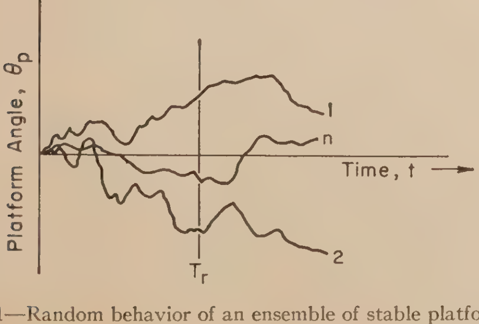

Fig. 1—Random behavior of an ensemble of stable platforms.

OPERATION OF STABLE PLATFORMS

A stable platform is basically a carriage for accelerometers or other equipment which is isolated from the vehicle's angular motions by means of appropriate gimbals. At least two, and sometimes three, gimbals in addition to the platform itself are used to permit the vehicle to have sufficient freedom for angular maneuver without disturbing the platform. If the platform suspension system were completely free of all friction and if the gimbals making up the suspension system were without inertia, then the mass of the platform would maintain its initial alignment in inertial space irrespective of vehicle maneuvers. However, in a practical system, three or four servomechanisms are used to drive the gimbals and platform in order to overcome friction and inertia effects. These servomechanisms are operated by error signals derived from gyroscopic instruments mounted on the platform.

In order to study the fundamental behavior of a stable platform, a simplified version will be used. Fig. 2 shows a single-degree-of-freedom platform driven by a single servomotor and amplifier from an error signal derived from a single-degree-of-freedom gyroscope of the integrating type. The function of this platform is to remain stationary in space in spite of vehicle maneuvers calling for angular rotation around the vertical axis c_3. It will be assumed that there is no angular motion around either of the other two orthogonal axes c_1 and c_2. Fig. 3 is a more detailed view of the integrating gyroscope which is used to sense angular motion of the platform and thereby to provide an electrical signal for actuating the platform servomechanism. This gyroscope operates on the principle that a torque about the gimbal axis (p_2 in Fig. 2) is required to balance the precession of the angular momentum of the gyroscope caused by a platform angular rate. This balancing torque is provided by viscous friction between the gimbal and the instrument case, which is rigidly attached to the platform. This means that an angular rate of the platform will cause an angular rate of the gimbal. However, any tilt angle θ_g of the gimbal which is built up as the result of the gimbal angular rate is detected by an electrical pickup which sends a signal to the amplifier driving the servomotor. As a result of this signal, the servomotor causes the platform to "unwind" and thereby restore the gimbal to its neutral position. By design, the tilt angle is kept small for all normal operating conditions.

Other kinds of gyroscopes could be used for sensing platform angular motion and generating correction signals. However, the single-degree-of-freedom integrating gyroscope shown in Figs. 2 and 3 is commonly used for this purpose in today's art. The perfection of this type of instrument has brought about a considerable improvement in the performance of stable platforms. This improvement has resulted primarily from the flotation of the gimbal by the damping fluid, thereby making possible a nearly frictionless suspension of the gimbal in the instrument housing. That is, flotation has eliminated to a very large degree coulomb-friction effects which previously introduced large uncertainties in instrument and platform performance. It is not the purpose of this paper to go into the intricacies of the analysis and the design of integrating gyroscopes, these being well covered by the literature.[4]

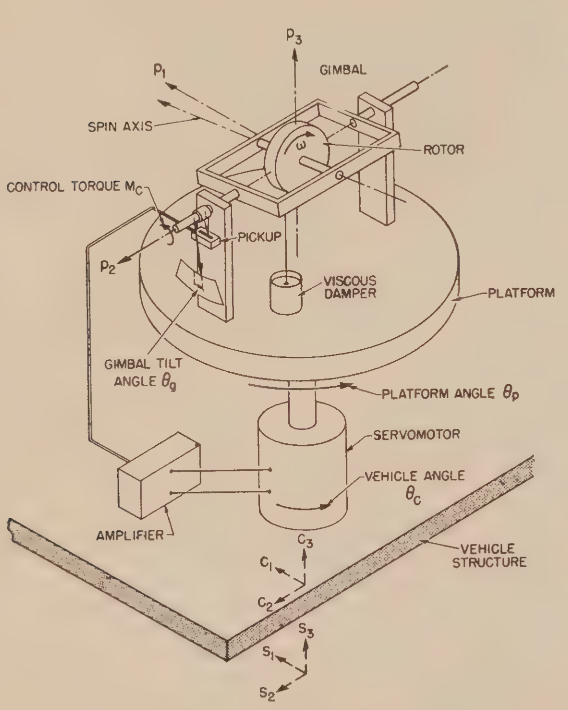
P3
GIMBAL
P1
SPIN AXIS
ROTOR
ω
CONTROL TORQUE MC
PICKUP
P2
VISCOUS DAMPER
PLATFORM
GIMBAL TILT ANGLE θg
PLATFORM ANGLE θp
SERVOMOTOR
VEHICLE ANGLE θc
AMPLIFIER
C3
C1
C2
VEHICLE STRUCTURE
S3
S1
S2

Fig. 2—Schematic diagram of gyroscopically-stabilized single-degree-of-freedom platform.

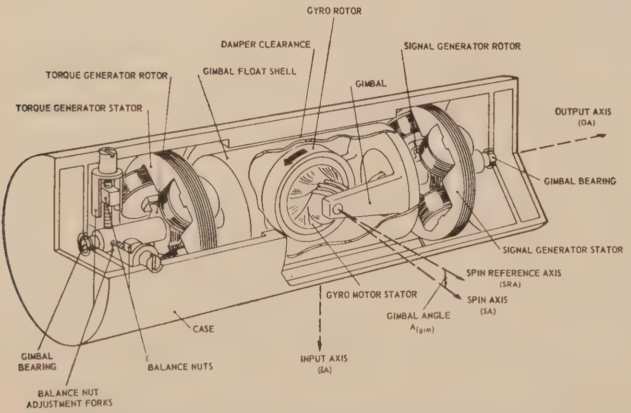
GYRO ROTOR
DAMPER CLEARANCE
SIGNAL GENERATOR ROTOR
TORQUE GENERATOR ROTOR
GIMBAL FLOAT SHELL
GIMBAL
TORQUE GENERATOR STATOR
OUTPUT AXIS (OA)
GIMBAL BEARING
SIGNAL GENERATOR STATOR
SPIN REFERENCE AXIS (SRA)
GYRO MOTOR STATOR
SPIN AXIS (SA)
GIMBAL ANGLE A(gim)
CASE
GIMBAL BEARING
BALANCE NUTS
INPUT AXIS (IA)
BALANCE NUT ADJUSTMENT FORKS

Fig. 3—Pictorial view of floated, integrating gyroscope. (Courtesy, M.I.T. Instrumentation Laboratory.)

In order to clearly define the angles which will be referred to throughout the remainder of the paper, Fig. 4 shows three sets of rectangular coordinate axes. The set s_j refers to axes fixed in inertial space. The set c_j is attached to the vehicle and the set p_j to the platform. Because we are considering a simplified case of a single-degree-of-freedom platform, the axes s_3, c_3, p_3 are assumed aligned. The angle θ_p is the angle between the s_2 axis and the p_2 axis; this angle measures how far the platform has turned with respect to inertial space. The angle θ_c measures how far the vehicle has turned with respect to inertial space and is the angle between the s_2 and c_2 axes.

Analysis of Platform Behavior

Ideally, the system shown in Fig. 2 should operate to produce a platform angle at all times equal to the desired angle which in this paper will be assumed to be zero. In practice, the platform angle θ_p will depart from zero with the passage of time. This departure is random, since all systematic errors are assumed to be eliminated, and it is most easily characterized in terms of the standard deviation σ_{θ_p} of an ensemble of platforms.

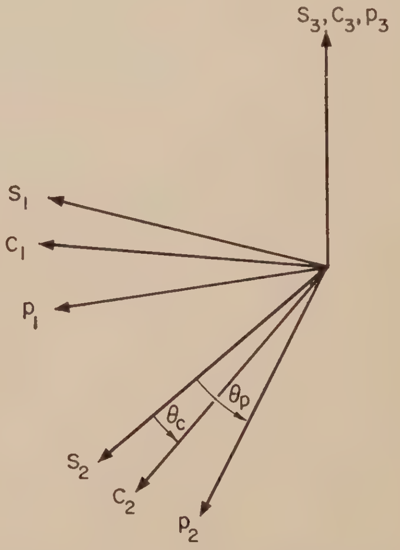
S3, C3, P3
S1
C1
P1
θp
θc
S2
C2
P2

Fig. 4—Orientation of reference axes showing platform angle θ_p and vehicle angle θ_c.

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[4] C. S. Draper, W. Wrigley, and L. R. Grohe, "The Floating Integrating Gyro and its Application to Geometrical Stabilization Problems on Moving Bases," Institute of Aeronautical Sciences, SMF Fund Paper No. FF-13; presented in January, 1955.

How do factors such as thermal fluctuations in the gyroscope, spin-axis bearing noise, servomotor-torque fluctuations, and vehicle angular maneuvers affect the standard deviation $\sigma_{\theta p}$? The analysis that answers this question is based on Fig. 5, which shows a block diagram of the platform system of Fig. 2. In this diagram, s stands for the Fourier-transform complex variable. The summing point within the integrating gyroscope block represents torque summation around the gimbal axis. A control torque M_c for positioning the platform is balanced against the gyroscopic torque to yield a net torque which tilts the gimbal. However, in order to account for thermal and other fluctuations, a torque fluctuation M_f is added at this point. The net torque tilts the gimbal at a rate determined by the viscous-damping coefficient f_g. This tilt velocity occurs with a time lag τ_g which is equal to the moment of inertia J_g of the gimbal about its axis divided by f_g. Integration (represented by division by s) of the tilt rate yields the gimbal tilt angle θ_g.

The servomechanism of Figs. 2 and 5 is assumed to be a dc motor which is directly connected to the platform and whose armature voltage is controlled by an amplifier. Stabilization is provided by the armature back emf or by its synthetic equivalent derived from tachometric measurement of the armature velocity. The motor-driving torque is assumed to be linearly related to the gimbal tilt angle and is given by $k_g\theta_g$, where k_g is the over-all gain of the pickup and amplifier of Fig. 2. This torque is summed with a platform torque disturbance and a torque equivalent to the vehicle's rate of change of angle in order to form the net torque available to drive the platform relative to inertial space. The platform-torque disturbance accounts for noise in the servoamplifier, friction effects and load disturbances acting on the platform. The net torque divided by the effective damping coefficient f_p of the motor gives the platform's angular velocity Ω_p, providing the time lag associated with the motor and platform moment of inertia J_p is accounted for. The time constant τ_p is the inertia J_p divided by the damping f_p. It is assumed that the reaction torque of the motor on the vehicle produces negligible motion of the latter. The angular rate Ω_p of the platform feeds back to the gyroscope gimbal through the angular momentum H of the gyro rotor. This closes the platform-stabilization loop. The platform angle θ_p is simply the integral of the angular rate Ω_p.

Long-term errors in the platform angle can be corrected for by a reset mechanism, schematically shown in Fig. 5. Assuming that some independent means of determining a space reference angle θ_s, such as a star-tracker, is available, the error between this angle and the platform angle can be used to generate a control torque M_c which drives the platform (through the gyroscope) to the null condition. For reasons of convenience or necessity, the external reference angle may be available only intermittently, and this accounts for the switch in Fig. 5. Another way of asking the question concerning fluctuation effects is: How long may the period T_r between platform resets be before the standard deviation $\sigma_{\theta p}$ of the platform angle exceeds an assigned limit?

The block diagram of Fig. 5 can be manipulated into the form of Fig. 6, where the influences of the several sources of platform-rate fluctuations are indicated by means of transmission functions terminating at a common summing point to form the platform rate Ω_p. From Fig. 5, these transmission functions are found to be

$$W_g(s) = \frac{H^{-1}}{K_v^{-1}\tau_g\tau_p s^3 + K_v^{-1}(\tau_g+\tau_p)s^2 + K_v^{-1}s + 1}$$

$$W_d(s) = \frac{(K_v f_p)^{-1}(\tau_g s + 1)s}{K_v^{-1}\tau_g\tau_p s^3 + K_v^{-1}(\tau_g+\tau_p)s^2 + K_v^{-1}s + 1} \qquad (1)$$

$$W_c(s) = \frac{K_v^{-1}(\tau_g s + 1)s^2}{K_v^{-1}\tau_g\tau_p s^3 + K_v^{-1}(\tau_g+\tau_p)s^3 + K_v^{-1}s + 1}$$

where the velocity constant K_v of the servomechanism is

$$K_v = \frac{k_p}{f_p} \qquad (2)$$

and the other constants are as defined above. (A summary of the nomenclature appears as Appendix I.)

Because it has been assumed that no systematic errors exist and that the desired platform angle is zero, only random fluctuations M_f of gimbal torque, platform torque M_d, and vehicle angle θ_c will be present. These fluctuations cause a random fluctuation of the platform angular rate Ω_p. Although these fluctuations have stationary probability distributions, those of the platform angle θ_p do not because initially the angle is

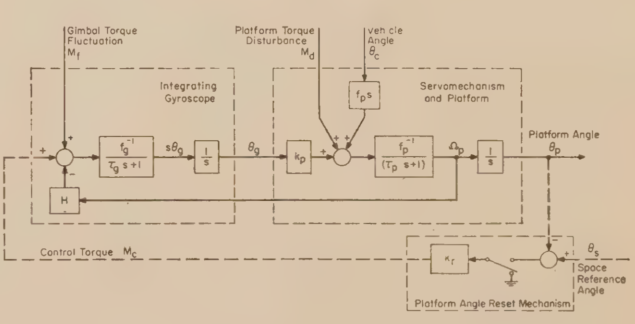
Gimbal Torque Fluctuation M_f
Platform Torque Disturbance M_d
vehicle Angle θ_c
Integrating Gyroscope
Servomechanism and Platform
$f_p s$
+
+
$\frac{f_g^{-1}}{\tau_g s+1}$
$s\theta_g$
$\frac{1}{s}$
θ_g
k_p
$\frac{f_p^{-1}}{(\tau_p s+1)}$
Ω_p
Platform Angle θ_p
H
Control Torque M_c
κ_r
θ_s
Space Reference Angle
Platform Angle Reset Mechanism

Fig. 5—Block diagram of stable-platform system.

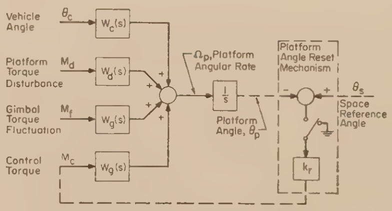
Vehicle Angle θ_c
$W_c(s)$
Platform Torque Disturbance M_d
$W_d(s)$
Gimbal Torque Fluctuation M_f
$W_g(s)$
Control Torque M_c
$W_g(s)$
+
Ω_p, Platform Angular Rate
$\frac{1}{s}$
Platform Angle, θ_p
Platform Angle Reset Mechanism
θ_s
Space Reference Angle
k_r

Fig. 6—Simplified block diagram of stable-platform system.

set to zero and then, with the lapse of time, the angle wanders off from zero, as shown in Fig. 1. This situation is a nonstationary one and, unless a certain condition prevails, the standard deviation of the platform angle will grow without bound as a function of time because of the integration in going from rate to angle. This phenomenon is closely related to the random walk problem.[5]

The basic problem is best described in terms of Fig. 7

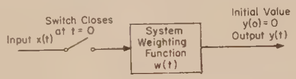

Fig. 7—Basic time-varying system used in platform stabilization.

where a linear system characterized by its weighting function $w(t)$ is initially at rest. After $t=0$, it is connected to random input signal $x(t)$, which is drawn from a stationary process. $x(t)$ has zero mean value. The output $y(t)$, which was initially zero, assumes random values for time positive. How can the output be characterized as a function of time? By means of ensemble averages the rms value (or standard deviation) of the output can be expressed in terms of the auto-correlation function of the input and the system weighting function. In the frequency domain the result can be expressed as[6]

$$\sigma^2(T_r) = \frac{1}{j}\int_{-j\infty}^{j\infty} ds W(-s, T_r)W(s, T_r)\Phi_{xx}(s) \tag{3}$$

where $\Phi_{ss}(s)$ is the power-density spectrum of the input $x(t)$ and

$$W(s, T_r) = \int_0^{T_r} dte^{-st}w(t) \tag{4}$$

$W(s, T_r)$ is a time-varying transmission function.

A general analysis usually stops at this point because of the complexity of the time-varying transmission functions and the resulting difficulty in carrying out the integration (3). However, because the $w(t)$ of interest in the case of stable platforms is a simple integration, it is possible to carry the analysis further. As shown in Appendix II, the unbounded term in $\sigma^2(T_r)$ can be evaluated by contour-integration methods. Since all other terms are bounded, one obtains the general result

$$\lim \sigma(T_r) = [2\pi\Phi_{xx}(0)]^{1/2}T_r^{1/2} \text{ as } T_r \to \infty \tag{5}$$

which shows that the long-term growth of the standard deviation of the output of an integrator is proportional to the square root of the product of time and the amplitude of the input power-density spectrum at zero frequency. This result will now be used to determine the standard deviation $\sigma_{\theta p}$ of the platform angle for thermal noise in the gyroscope as the only fluctuation.

THERMAL NOISE

Just as a resistor is a source of thermal noise, so is a viscous damper in a mechanical system. The noise in systems containing resistors, whether mechanical or electrical, may be calculated if we assume each resistor to have a white-noise source embedded within itself. The power-density spectrum of the noise associated with a mechanical resistor or damper is

$$\Phi_{MfT}(s) = \frac{KT}{\pi} f_g. \tag{6}$$

Here the subscripts stand for the thermal fluctuation moment, since this is the spectrum of the moment that thermal agitation produces within the damping fluid and that is effective in driving the gimbal. Here K is Boltzmann's constant and T is the absolute temperature; f_g is the coefficient of viscous damping associated with gimbal rotation.

If this thermal noise is the sole source of fluctuations, then from Fig. 6 we see that the power-density spectrum of the platform angular rate caused by thermal fluctuation moments is

$$\Phi_{\Omega pT}(s) = W_g(-s)W_g(s)\Phi_{MfT}(s). \tag{7}$$

This relationship follows from the general properties of linear systems that are subjected to stochastic signals. Using (1), (6), and (7), one obtains

$$\Phi_{\Omega pT}(0) = \frac{KT}{\pi}\,\frac{f_g}{H^2}\,.$$

Thus, from (5), the thermal noise influence on the platform position is expressed by

$$\sigma_{\theta pT}/\sqrt{T_r} = H^{-1}\sqrt{2KTf_g} \tag{8}$$

providing that T_r is large. In these expressions, H is the angular momentum of the gyroscope rotor and the subscript T is used to denote thermal fluctuation.

Let us now establish an order of magnitude for the platform fluctuation using the above general result. Substituting in the parameter values for a typical gyroscope from Table I and putting in the numerical value for Boltzmann's constant, we get the following expression:

$$\frac{\sigma_{\theta pT}}{\sqrt{T_r}} = \frac{\sqrt{2(1.38 \times 10^{-16})350(2.0 \times 10^4)}}{1.0 \times 10^5}$$

$$= 0.440 \times 10^{-9}\,\frac{\text{rad}}{\text{sec}^{1/2}}\,. \tag{9}$$

This result can be made more meaningful by consideration of how long a time it would take for the standard deviation of the platform angle to grow to one minute of arc assuming that the only source of fluctuations is thermal agitation of the damping fluid. This time turns

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[5] S. Chandrasekhar, "Stochastic problems in physics and astronomy," *Revs. Mod. Phys.*, vol. 15, pp. 2–89; January, 1943.

[6] See, for example, J. H. Laning, Jr. and R. H. Battin, "Random Processes in Automatic Control," McGraw-Hill Book Co., Inc., New York, N. Y. pp. 238–239; 1956.

TABLE I

Parameters for a Typical Integrating Gyroscope[7]

Rotor moments of inertia (around spin axis)	J_r	40 gm cm^2
Rotor mass	m_r	25 gm
Rotar angular velocity	ω_r	2500 rad/sec
Rotor angular momentum	H	1.0×10^5 dyne cm sec/rad
$\left[\text{Amplitude of power-density spectrum of bearing axial wander at zero frequency}\right]^{\frac{1}{2}}$	η_b	1.0×10^{-6} cm/(rad/sec)$^{1/2}$
Moment of inertia of gimbal (including enclosed equipment)	J_g	100 gm cm^2
Viscous-damping coefficient of gimbal	f_g	2.0×10^4 dyne cm sec/rad
Operating temperature	T	350° K

out to be 13,900 years. Thus, it is seen that the potential performance of a gyroscopically stabilized platform is very great indeed.

Published performance data[7] indicate that under laboratory conditions the standard-deviation figure $\sigma_{\theta pT}/\sqrt{T_r}$ is of the order of 5.0×10^{-6} rad sec$^{-1/2}$. This means that the realized performance of gyroscopes, at least to the extent that published data are available, is several orders of magnitude below that potentially available from the viewpoint of thermal noise. As electronics engineers, we know that radio receivers and galvanometers[8] are thermally limited, and it seems natural to seek similar performance from other electrical and electromechanical instruments such as gyroscopes.

Influence of Other Fluctuations

The large discrepancy between the published performance and the potentially-available performance, if thermal fluctuations are taken to be the ultimate limitation, suggests that other influences may be sources of the much larger fluctuations which are apparently limiting existing gyroscopes. In discussion of other possible sources, vehicle maneuver angles θ_c and platform torque disturbances M_d are first eliminated from consideration, since the vehicle angular velocity $\dot{\theta}_c(t)$ and the torque disturbances must be characterized by power-density spectra which are finite at zero frequency. This follows from the fact that the stochastic components of these signals, which are the only components being considered, have no dc terms and also do not wander off from zero like integrated noise signals. From the transmission functions, (1), it is noted that $W_d(0)$ is zero and that $s^{-1}W_c(s)$, for $s=0$, is also zero. This means that, from Fig. 6, the power-density spectra of the components of the platform velocity caused by these signals is zero at zero frequency and, therefore, there can be no long-term growth of the standard deviation of the platform position from these sources.

Returning to gimbal-torque fluctuations, it would appear that there are a number of possible sources in addition to thermal noise. One is the control torque generator and associated equipment. Although this may be important in present gyroscopes, there is no theoretical reason why fluctuations from this source cannot be made comparable to the thermal-noise fluctuations in the damping fluid. Therefore, this source will not be discussed.

Another source is the interaction of acceleration forces (including gravity) with center-of-mass wander of the rotor caused by bearing noise. Almost all of the gyroscopes manufactured today employ ball-bearings for supporting the rotor. The aspect of bearing noise that affects gyroscope performance is not the acoustical one but rather the lower-frequency wander of spin-axis location. In the presence of gravity and acceleration fields, stochastic movement of the rotor center along the spin axis produces random moments that result in a random drift of the platform.

In order to arrive at an order of magnitude for the effect of bearing noise, information on the low-frequency wander is needed. A limited amount of test data available to the writer indicate that the power-density spectrum of the axial displacement of precision ball bearings in the sizes used in gyroscopes is relatively flat near zero frequency. Furthermore, the amplitude η_b^2 of the spectrum in this region is of the order of

$$\left[\frac{10\ \text{m}\mu}{(\text{rad/sec})^{1/2}}\right]^2.$$

The gimbal moment caused by axial displacement of the rotor is

$$M_{fb} = m_r a_z \alpha_b \tag{10}$$

where m_r is the rotor mass, a_z is the acceleration-gravity component that is normal to the spin and gimbal axes, and α_b is the axial displacement of rotor caused by the bearings. From Fig. 6 and the data given above, the zero-frequency value of the sprectrum $\Phi_{\Omega pb}$ of the platform rate caused by bearing noise is

$$\Phi_{\Omega pb}(0) = (m_r a_z \eta_b)^2 W_g{}^2(0). \tag{11}$$

Using (1) and (5) together with (10), we get

$$\frac{\sigma_{\theta pb}}{\sqrt{T_r}} = (2\pi)^{1/2}\left(\frac{m_r a_z \eta_b}{H}\right). \tag{12}$$

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[7] The Kearfott Company, Inc., "Floated rate integrating gyros," *Control Engrg.*, vol. 6, p. 134; October, 1959. This advertisement gives standard-deviation data for Kearfott Model M2516-01A-A gyroscopes. Knowing that the standard-deviation data are based on readings approximately eight minutes apart permits one to arrive at the estimated figure cited above. The data of Table I approximately correspond to the parameters of this gyroscope.

The Sperry Gyroscope Company's SYG-500 floated integrating gyroscope is described in its Publication Number CA-60-0001 dated November, 1959. The published performance curves for this instrument, which has five times the angular momentum of the Kearfott instrument, correspond to a standard deviation figure that is substantially comparable to that quoted in text.

[8] G. Ising, "A natural limit for the sensibility of galvanometers," *Phil. Mag.*, vol. 1, pp. 827–834; April, 1926.

For a 1-g acceleration, a gyroscope with the parameters of Table I (next page) is characterized by an acceleration-bearing-noise standard deviation of

$$\frac{\sigma_{\theta pb}}{\sqrt{T_r}} = \frac{(2\pi)^{1/2}25(980)1 \times 10^{-6}}{1.0 \times 10^5}$$

$$= 0.614 \times 10^{-6} \frac{\text{rad}}{\text{sec}^{1/2}}. \tag{13}$$

This figure is a factor of ten less than the standard-deviation figure inferred from published performance data for a gyroscope with similar parameters. Thus, bearing noise alone does not fully explain the published performance but it comes much closer to doing so than does thermal noise. It should be noted that in space flight accelerations will be near zero, causing bearing-noise fluctuations associated with acceleration to be much reduced.

In addition to the axial-wander phenomena, bearing noise may produce randomness of the platform angle through other mechanisms, either singly or in combination. Dynamic unbalance, fluctuating gyroscopic torques, and bearing nonlinearities are examples. It is recommended that future studies of gyroscopically-stabilized platforms include analyses of these effects with the objective of improving the correlation between theory and observed behavior.

DISCUSSION

A gyroscopically-stabilized platform has been shown to drift away from its desired angular orientation even though all systematic errors have been eliminated or compensated for. This drift is random in nature and is caused by randomness of platform angular rate. Angular-rate randomness presumably is the result of many influences, but the most significant ones are those that produce power-density spectra of the platform rate that are non-zero for zero frequency. Such influences produce random errors in platform position that increase with the square root of time. Analysis shows that, for a platform stabilized by an integrating gyroscope, platform-torque disturbances and vehicle angular motions are not significant in the build-up of platform error. However, certain random components of gyroscope gimbal torque do cause error build-up. In particular, the error build-up has been quantitatively related to torques produced by thermal fluctuations (Brownian movement) in the damping fluid and to torques produced by acceleration and gravity acting on center-of-mass shifts caused by spin-axis bearing noise.

The error build-up caused by thermal fluctuations in the damping fluid is small. On the basis of parameter values for a medium-sized gyroscope, more than 100 centuries would go by before the platform-error standard deviation would exceed one minute of arc if thermal fluctuations were the only source of error. Published data for gyroscopes in current production imply error performance that is inferior to an ideal thermally-limited gyroscope by about four orders of magnitude (or by eight orders of magnitude if the time to build up a prescribed standard deviation is the criterion).

The error build-up caused by mass shifts induced by ball-bearing noise is quite large when the earth's gravitational field or an equivalent acceleration is acting on the instrument. However, this source of error does not fully explain the published test data referred to above. It is therefore concluded that additional explanations for these data should be sought.

The major conclusion of this paper is that no fundamental barrier to a vast improvement in stable platform performance exists if the same phenomenon that limits the sensitivity of radio receivers and galvanometers also proves to be the basic limitation on gyroscope performance. This phenomenon is thermal noise and, so far, inertial-guidance engineers have not been limited by it because other, less fundamental, sources of fluctuations have been so much larger. Stable platforms that are used on space vehicles may perform somewhat better than those used on earth-bound vehicles, because the effect of one of these other sources will be greatly reduced in view of the diminished influence of acceleration and gravity.

It should not be concluded from this paper that it is possible to achieve the levels of performance that are indicated by the thermal-noise limitation either by existing approaches or by any new scheme that may be devised in the future. The requirements on systematic error elimination become increasingly severe as the random errors are reduced. To make a thermally-limited platform of practical use requires the systematic component of the platform-rate error to be of the order of one second of arc per century, for the example given above.

On the other hand, it is reasonable to conclude from this paper that a continued effort to improve stable-platform performance is justified. Such an effort should be twofold. First, the improvement of existing gyroscopes and associated equipment should be continued. Incorporation of hydrodynamic (gas) bearings is an example of one step in this direction. Second, the search for new ideas for obtaining a stable angular reference should be pressed forward with vigor. Each of these new ideas should be analyzed theoretically, and those which look promising should be put to epxerimental test.

APPENDIX I

NOMENCLATURE

a_z = effective acceleration (including gravity) normal to gimbal and spin axes
e = base of natural logarithms
f_g = viscous-damping coefficient of gimbal
f_p = platform-servomotor damping
H = angular momentum of gyro rotor
J_g = gimbal moment of inertia
J_p = platform moment of inertia
J_r = moment of inertia of rotor

j = square root of minus one

K = Boltzmann's constant

K_v = velocity constant of platform servomechanisms

k_p = platform-servomechanism gain (torque per unit angle of gimbal tilt)

M_c = control torque applied to gimbal axis

M_d = platform-torque disturbance

M_f = torque fluctuation about gimbal axis

m_r = mass of gyro rotor

s = complex frequency used in Fourier transforms

T = absolute temperature

T_r = time to platform position reset

t = time

$W(s, T_r)$ = filter time-varying transmission function

$w(t)$ = filter-weighting function

x = input of filter

y = output of filter

α_b = axial displacement of rotor caused by bearing noise

η_b^2 = amplitude, at zero frequency, of the power-density spectrum of rotor axial displacement caused by bearing noise

θ_c = vehicle angle with respect to inertial space

θ_g = gimbal-tilt angle

θ_p = platform angle with respect to inertial space

σ = standard deviation of filter output

σ_{θ_p} = standard deviation of platform angle θ_p

$\Phi_{xx}(s)$ = power-density spectrum of input to filter

$\Phi_{\Omega_p}(s)$ = power-density spectrum of platform angular rate

Ω_p = platform angular rate with respect to inertial space

ω_r = wheel-spin angular velocity.

APPENDIX II

DERIVATION OF (5) FOR $\sigma(T_r)$

The weighting function $w(t)$ of Fig. 7 that corresponds to an integrator is

$$\left.\begin{aligned} w(t) &= 1 \qquad \text{for } t \geq 0 \\ w(t) &= 0 \qquad \text{for } t < 0 \end{aligned}\right\}. \tag{14}$$

Subsituting this into (4) yields

$$W(s, T_r) = \frac{1 - e^{-sT_r}}{s}. \tag{15}$$

Placing this time-varying transmission function into (3) gives

$$\sigma^2(T_r) = \frac{1}{2\pi j} \int_{-j\infty}^{j\infty} dsF(s, T_r) \tag{16}$$

where

$$F(s, T_r) = \lim_{\epsilon \to 0} 2\pi \left[\frac{e^{+sT_r} - 2 - e^{-sT_r}}{(s - \epsilon)(s + \epsilon)} \right] \Phi_{xx}(s). \tag{17}$$

The splitting of the double-order pole at $s = 0$ into two first-order poles at $\pm\epsilon$ is justified by regarding the integration that gives rise to this pole as the limit of the weighting function

$$\left.\begin{aligned} w(t) &= e^{-\epsilon t} \qquad \text{for } t \geq 0 \\ w(t) &= 0 \qquad \text{for } t < 0 \end{aligned}\right\} \tag{18}$$

that is reached when $\epsilon = 0$.

A line integral of the type (16) can be evaluated by separating the integrand into two components:

$$F_1(s, T_r) = \lim_{\epsilon \to 0} 2\pi \left[\frac{e^{sT_r} - 1}{(s - \epsilon)(s + \epsilon)} \right] \Phi_{xx}(s)$$

and

$$F_2(s, T_r) = \lim_{\epsilon \to 0} 2\pi \left[\frac{e^{-sT_r} - 1}{(s - \epsilon)(s + \epsilon)} \right] \Phi_{xx}(s). \tag{19}$$

The contribution of each component is evaluated separately by contour integrals consisting of the imaginary axis and large semicircles centered on the origin. Since T_r is positive and real, a semicircle in the left half-plane is used for F_1 and in the right half-plane for F_2. This choice of contours ensures, in each instance, that the contribution to the integral along the semicircle approaches zero as the radius approaches infinity. Then, use of the residue theorem shows that

$$\sigma^2(T_r) = \sum_m K_{1m} - \sum_n K_{2n} \tag{20}$$

where K_{1m} is the residue of F_1 at the pole at s_m in the left half-plane and K_{2n} is the residue of F_2 at the pole at s_n in the right half-plane. Each summation includes all of the poles of a particular function in its indicated half-plane.

The residues associated with poles of $\Phi_{xx}(s)$ contribute terms of the type $c(1 - e^{-aT_r})$ where c is a constant. These are bounded as T_r approaches infinity. The only unbounded terms arise from the poles at $\pm\epsilon$. Let the residues at these poles be indicated by $K_{1\epsilon}$ and $K_{2\epsilon}$ respectively for the functions F_1 (pole at $-\epsilon$) and F_2 (pole at $+\epsilon$). Then,

$$\lim_{T_r \to \infty} [\sigma^2(T_r)] = \lim_{\epsilon \to 0} [K_{1\epsilon} - K_{2\epsilon}]. \tag{21}$$

But

$$\begin{aligned} K_{1\epsilon} &= 2\pi \left[\frac{1 - e^{-\epsilon T_r}}{2\epsilon} \right] \Phi_{xx}(-\epsilon) \\ -K_{2\epsilon} &= 2\pi \left[\frac{1 - e^{-\epsilon T_r}}{2\epsilon} \right] \Phi_{xx}(\epsilon). \end{aligned} \tag{22}$$

Substituting these values into (20) and taking the limit as ϵ goes to zero yields (5).[9]

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[9] W. B. Davenport, Jr. and W. L. Root, "An Introduction to the Theory of Random Signals and Noise," McGraw-Hill Book Co., Inc., New York, N. Y., p. 69, (4–83); 1958. This source gives an equivalent expression to (5) in the time domain.

The Astronautic Chart[*]

ROY C. SPENCER†, FELLOW, IRE

Summary—**The Astronautic Chart is a nomograph or alignment chart so arranged that a single straight line marks off values of the velocity, mass, mean distance, period, and acceleration of any two-body orbiting system. It is illustrated with numerous examples of orbits of planets about the sun, moons about their planets, and artificial earth satellites.**

All scales give correct values at the extremities of the minor diameter of the elliptical orbit. In the case of binary stars where the masses are comparable, the scales also give correct values of the *total mass*, *total separation*, *relative velocity*, and *relative acceleration*.

INTRODUCTION

LAUNCHING of the twenty-two artificial earth satellites and lunar and space probes during the first two years of the space age has again focused attention of students and scientists on the laws of Kepler and Newton that control the paths of the planets around the sun and of natural satellites around their planets. These laws apply as well to the motions of artificial satellites.

The specialist in celestial mechanics or space travel deals with orbit problems that become very intricate when precise answers are needed. But a general understanding of the physical laws and their application is much easier to attain. In fact, with the aid of the Astronautic Chart[1–4] inserted between the pages of this issue, the would-be astronaut can quickly obtain an appreciation of the motions within the solar system. This simple graphical device shows at a glance the interrelations among distances, orbital periods, and masses, as well as velocities and accelerations.

The diagram is a nomograph or alignment chart, so arranged that a single oblique line gives the characteristics of a particular orbit. The oblique lines illustrate numerous systems of bodies in orbital motion; other lines may be drawn to solve problems concerning possible future satellites, or asteroid orbits.

Thus, in Fig. 1 the five vertical scales indicate the following, from left to right.

V is the mean orbital velocity, in kilometers per second. For a circular orbit, this is the constant speed of the moving body. If the orbit is an ellipse, V is the geometric mean (square root of the product) of the velocities at perihelion and aphelion, or at perigee and apogee.

M is the mass of the central body, in terms of the sun's mass as a unit. Strictly speaking, this is the combined mass of the two bodies, but for graphical purposes the mass of any planet or satellite can be regarded as negligible compared to the mass of its primary. (Only our moon has a mass as great as 1/80 of its central body.)

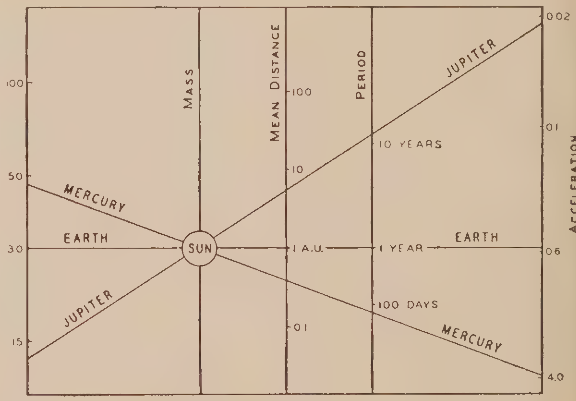

Fig. 1—Simplified portion of the Astronautic Chart. The earth-sun solution is horizontal.

a is the mean distance from the primary body, expressed in astronomical units or kilometers. In the case of an elliptical planetary orbit, this is the arithmetic mean (or average) of the perihelion and aphelion distances. One astronomical unit (A.U.) is the mean distance of the earth from the sun, about 93 million miles.

P is the period of orbital revolution, expressed in years at the top. This scale is successively changed to days, hours, and minutes to fit the short periods in the lower part of the chart. Since the mean angular velocity, $d\theta/dt$, is 360° divided by the period, we could construct such a scale collinear with the period scale. For example, a period of 90 minutes yields a mean angular velocity of 4° per minute.

g is the "mean" acceleration toward the central body, expressed in centimeters per second each second. For example, in the case of Jupiter, this is the velocity of free fall toward the sun, one second after starting from rest, of a body at Jupiter's distance from the sun.

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[*] Original manuscript received by the IRE, December 23, 1959. Revised from a paper published in *Sky and Telescope*, vol. XVII, no. 11; September, 1958.

† The Martin Co., Baltimore Div., Baltimore, Md. Formerly with Sylvania Electric Products Inc., Waltham, Mass.

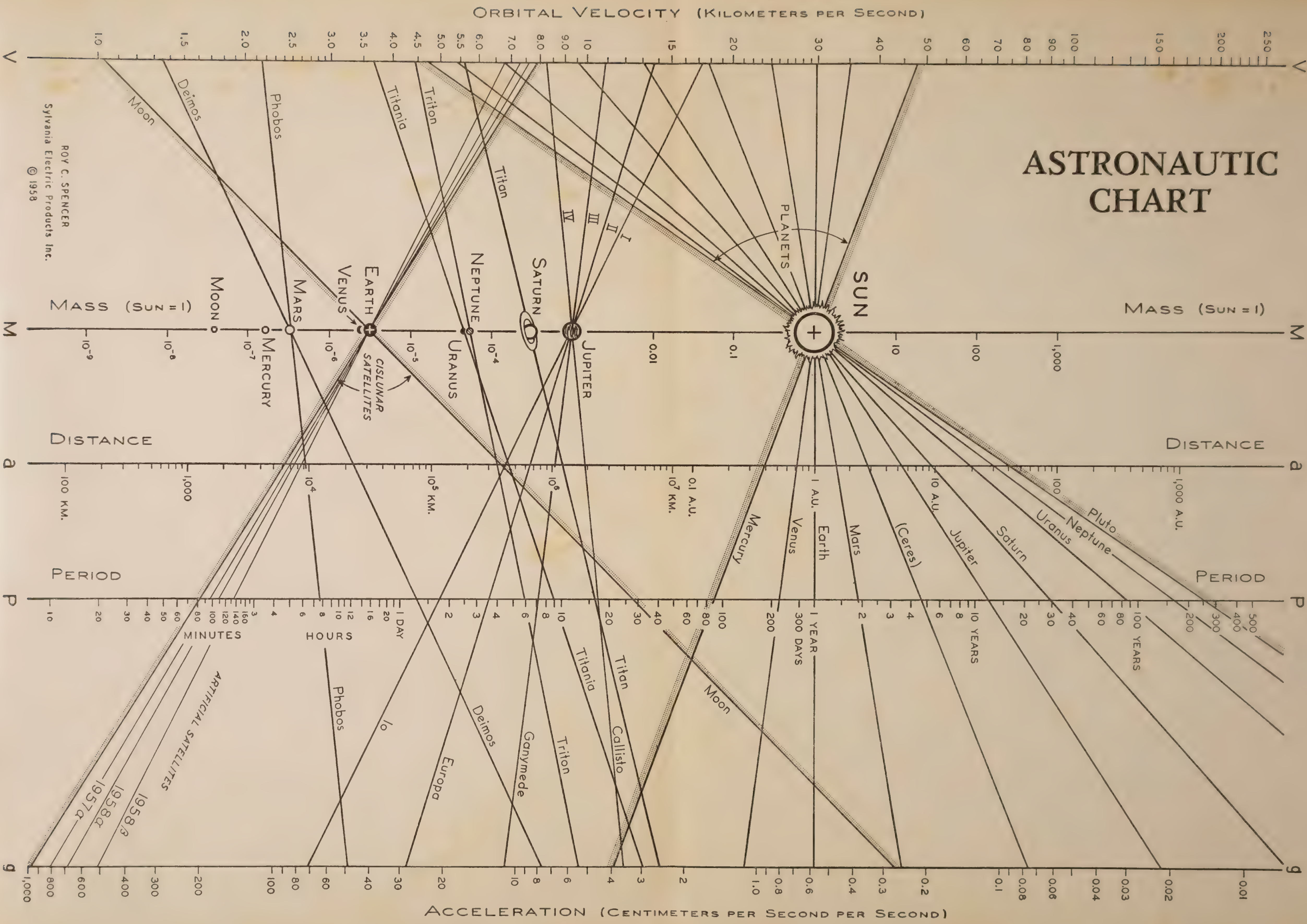
[1] R. C. Spencer, "The Astronautic Chart for Planets and Satellites," Sylvania Electric Products Inc., Waltham Labs., Waltham, Mass., Rept. No. A58-7B; March, 1958.

[2] R. C. Spencer, "Derivation of Formulas for the Astronautic Chart," Sylvania Electric Products Inc., Waltham Labs., Waltham, Mass., Rept. No. A58-7C; June, 1958.

[3] R. C. Spencer, "Fundamental Constants and Tables for Earth Satellites," Sylvania Electric Products Inc., Waltham Labs., Waltham, Mass., Rept. No. A58-7C; September, 1958.

[4] Numerical values of astrophysical constants used in references 1–3 were obtained from C. W. Allen, "Astrophysical Quantities," University of London, Athlone Press, London, Eng.; 1955.

ASTRONAUTIC CHART



ROY C. SPENCER
Sylvania Electric Products Inc.
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USING THE CHART

As an example of the use of the Astronautic Chart, consider the planet Saturn, which moves around the sun n a period of about 29½ years. Lay a straightedge across the chart, passing through the points marked "sun" on the M scale and just below 30 years on the P scale. Extended to the left, this straight line shows that Saturn's orbital velocity is some 9½ kilometers per second. From the intersection with the middle scale, the mean distance of Saturn from the sun is about 9.5 astronomical units, and the right-hand scale shows that the planet's acceleration toward the sun is much less than 0.01 cm/second².

There are corresponding lines drawn through the sun for the other principal planets, from Mercury to Pluto, as well as for a representative asteroid, Ceres.

In the lower part of the chart, each planet is indicated at the proper place on the mass scale. Through the planet symbols are drawn straight lines giving chart solutions for some of their satellites. The line for Jupiter's brightest moon, III (Ganymede), provides the following information: orbital velocity, about 11 kilometers per second; distance from Jupiter, over a million kilometers; period, seven days; and acceleration toward the planet 11 cm/second².

There is quite an overlap for some members of the solar system in both acceleration and velocity. For instance, the acceleration of our moon toward the earth approximates that of Mars toward the sun. Also, the velocities of the earth's present artificial satellites are about the same as the orbital velocity of Uranus around the sun.

ARTIFICIAL SATELLITES

An important use of the chart is the solution of problems involving earth satellites, whether natural or artificial. Two shaded lines run diagonally through the earth symbol on the mass axis, one for the moon, the other for a hypothetical satellite that would just graze the earth's surface. The double triangle bounded by these lines is the chart area including all possible earth satellites closer to us than the moon, that is, the *cislunar* area.

Three actual satellites have been plotted, 1957α, 1958α and 1958β, showing the range of initial period of the earlier artificial satellites. A typical moon shot, consisting of a narrow elliptical orbit reaching out to the moon, would be indicated by a line from the earth to a point marking approximately half the moon's distance. The solution for the proposed "one-day" satellite, which will hover over a particular point on the equator, will be a line through the one-day period.

Space-travel enthusiasts who expect that some day man-made satellites will be circling other planets to observe them close at hand will find use for the chart of Fig. 2, where minimum satellites have been plotted for all planets except Pluto and Venus. Each such satellite is presumed to circle its primary just above the surface we see, whether that surface is solid, as on Mercury and Mars, or gaseous, as on Jupiter and Saturn.

The minimum-satellite velocities differ widely, yet their periods are of the same order, ranging from over four hours for a minimum satellite of Saturn to 84.5 minutes for one of the earth. This is because the period for a spherical planet depends only on the planet's density. All spheres with the earth's density would have minimum-satellite periods of 84.5 minutes. A sphere of ice, whether 10 miles in diameter or the size of Jupiter, would have a period of about three hours and 27 minutes for such a grazing moonlet. This raises the question, "Is the interior of Jupiter made of ice?"

On the full-sized Astronautic Chart, the extension of any minimum-satellite line to intersect the acceleration (g) scale indicates the surface gravity of the planet; for example, 980 cm/second² for the earth. (This approximation would be exact if the planet were spherical and nonrotating.)

Attempts will eventually be made to establish a *circumlunar satellite* orbit by slowing down the velocity of a rocket which is about to miss the moon's surface. The Astronautic Chart also serves to answer numerical questions about the orbits of such artificial satellites concerning the natural satellites of planets. As an example, a line has been drawn in the minimum-satellite chart for a minimum circumlunar vehicle. From this we see that a rocket ship just clearing the lunar surface would require about 110 minutes to make a trip around the moon. The reader may easily find the orbital velocity and period of a rocket revolving around the moon at a distance above its surface of, say, 900 kilometers (2638 kilometers from its center).

KEPLER'S AND NEWTON'S LAWS

The three middle scales for mass, mean distance, and period provide a solution for Kepler's third or harmonic law, which holds for elliptical as well as circular orbits:

$$\frac{a^3}{P^2} = \frac{GM}{4\pi^2} \tag{1a}$$

in which G is the constant of gravitation.

If the mass M were uniformly distributed throughout a sphere of radius a and density ρ, then $M = (4/3)\pi\rho a^3$. On substituting this in (1a), we obtain

$$\rho P^2 = 3\pi/G, \tag{1b}$$

indicating, as was mentioned earlier, that the mean density depends only on the period.

Design of the chart is facilitated by expressing the variables in (1a) in terms of the V and g that appear at

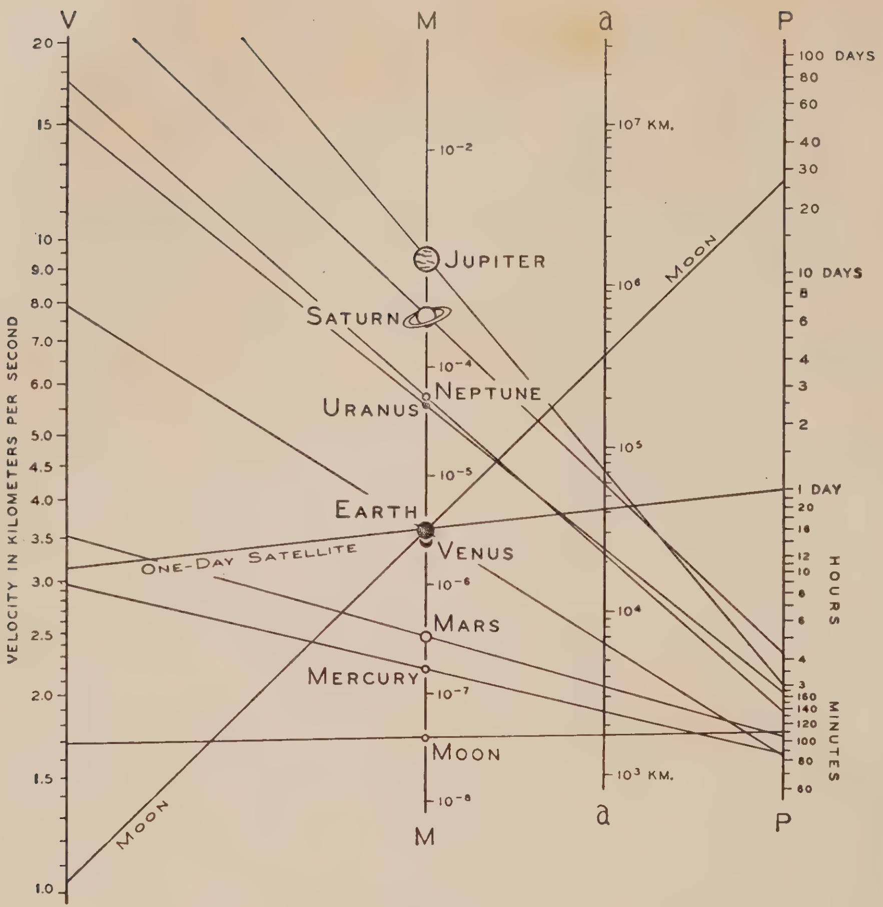

Fig. 2—Minimum satellite orbits of planets (and moon). Orbits of the one-day earth satellite and the moon have been included.

the sides of the chart. One writes the expressions for velocity and centripetal acceleration in the case of uniform circular motion discussed in elementary physics:

$$V = 2\pi a/P; \qquad g = V^2/a.$$

By rearrangement,

$$a = V^2/g; \qquad P/2\pi = a/V = V/g. \qquad (2,3)$$

Newton's Law of Universal Gravitation states that $g = GM/a^2$, whence

$$GM = a^2 g = V^4/g. \qquad (4)$$

Note that (2)-(4) are of the form V^n/g.

CONSTRUCTION OF THE CHART

Many readers are familiar with the multiplication nomograph or alignment chart for an equation of the form $z = xy$. Thus, in the simplest form, x and y are parallel logarithmic scales with the same logarithmic base, while the scale for z is placed *midway* between them with a logarithmic base *half as great*.

Actually, there is some flexibility in the choice of the logarithmic bases, as shown in the diagram of Fig. 3 for the case of $z = x^n y$. Choose any convenient base A for the cycle from 1 to 10 of the x scale. Then divide by n as shown on the left. On the right, any convenient parallel base B is shown for scale y. The intersection of the diagonals of the parallel line segments A/n and B are then marked off to find the *horizontal position* and *length* of the base C for z.

It can be shown from the construction that the position of the z scale is determined by

$$D = A/(A + nB) \qquad (5)$$

where D is the fraction of the distance from the left-hand scale to the right-hand one. Furthermore,

$$C = AB/(A + nB), \qquad (6)$$

where C is the base length (height) of the z scale.

These expressions can now be applied to (2), (3), and (4), each of which is of the form $z = V^n \times 1/g$. For convenience, let the logarithmic base for V, the left-hand scale of the Astronautic Chart, be of unit length, repre-

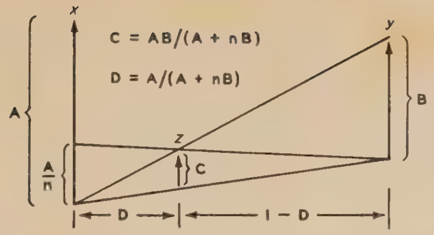

Fig. 3—Nomograph for $z=x^ny$, with C, A, and B the respective logarithmic scales.

ented by 1. For the right-hand scale, we adopt a base alf as long, represented by $\frac{1}{2}$. Our choices make $=1$ and $B=\frac{1}{2}$.

In (4), (2), and (3), n has the values 4, 2, and 1, for he ***M***, ***a***, and ***P*** scales, respectively. Substituting these alues in the expressions above for D and C gives able I for use in Fig. 4.

TABLE I

Scale	*V*	*M*	*a*	*P*	1/*g*
Position	0	1/3	1/2	2/3	1
Base	1	1/6	1/4	1/3	1/2

The reader who wishes to subdivide further the scales f the Astronautic Chart will find the proper values in ny scale of logarithms to the base 10.

Further information about nomograms may be found n such texts as Douglass and Adams,[5] and Mackey.[6]

Extension to Elliptic and Binary Orbits

The three middle scales naturally apply to elliptic rbits because they solve Kepler's third law. However, fter including in the chart the additional scales for ***V*** nd ***g*** on the basis of circular orbits, the author was greeably surprised to find that they were also exact at he extremities of the minor diameter of the ellipse. hus, in Fig. 5, the circular orbit is "equivalent" to the lliptical orbit in period and major diameter. The orbits ntersect at the extremities of the minor diameter BB′ f the ellipse, at which points the accelerations are qual and the velocities are the same in magnitude, hence the term "circular velocity."

Newton pointed out that, in a binary system consisting of two masses m_1 and m_2 revolving about their ommon center of gravity, Kepler's law still holds if M is the *sum* of the masses and a is the *mean separation*. It now appears that the ***V*** and ***g*** scales also hold at the extremities of the minor diameter of the *relative* ellipse, providing they represent *sums* of corresponding scalar magnitudes (or vector differences).

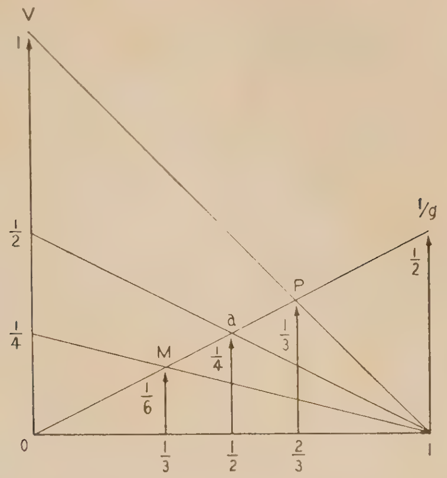

Fig. 4—Construction of the Astronautic Chart.

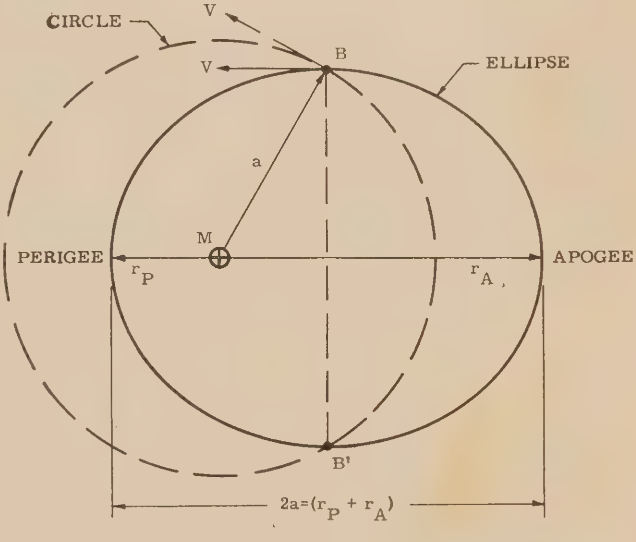

Fig. 5—Equivalent circular and elliptic orbits.

Originally the author had inserted several orbits of binary stars, such as Capella and Sirius, but later he decided to omit them in order to simplify the chart and restrict its illustrations to the solar system. But whether the reader is interested in earth satellites, interplanetary exploration, double stars, or a combination of these, the Astronautic Chart can be used to study them further.

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[5] R. D. Douglass and D. P. Adams, "Elements of Nomography," cGraw-Hill Book Co., Inc., New York, N. Y.; 1947.

[6] C. O. Mackey, "Graphical Solutions," John Wiley and Sons, nc., New York, N. Y.; 1936.

A Study of Natural Electromagnetic Phenomena for Space Navigation*

R. G. FRANKLIN† AND D. L. BIRX†, MEMBER, IRE

Summary—A study has been carried out for the United States Air Force investigating the use of natural electromagnetic radiation in the space environment for navigational purposes. Radiations from the sun, the stars, and interstellar space in both the visible and RF portions of the spectrum and also cosmic rays have been investigated.

Emphasis has been placed on the measurement of velocity in space utilizing the Doppler phenomenon. Equipment and techniques useful in deriving velocity information from Doppler shift measurements are described and figures for expected accuracy are derived. Other passive techniques having possible application to space navigation such as the measurement of total solar radiation and solar diameter are briefly discussed.

INTRODUCTION

THE Franklin Institute has been engaged in a study of natural electromagnetic radiation for a period of approximately one year. Radiations from the sun, the stars and interstellar space in both the optical and radio frequency portions of the spectrum have been investigated, with the aim of determining their value to space navigation, particularly in the measurement of velocity utilizing the Doppler phenomenon. In this paper, sources and techniques useful in deriving velocity information from Doppler shift measurements are described and figures for expected accuracy are derived. These data are then compared in accuracy with results of two other passive techniques, the measurement of total solar radiation and of solar diameter.

Whenever there is relative motion between a source of radiation and an observer, the radiation observed is shifted in wavelength an amount $\Delta\lambda$, which is proportional to the relative velocity according to the equation

$$\Delta\lambda = \lambda_1 - \lambda_2 = \frac{v\lambda_1}{c}, \tag{1}$$

where

v = relative velocity of source with respect to observer,
c = velocity of light,
λ_1 = wavelength of radiation observed with no relative motion,
λ_2 = wavelength observed with relative motion.

This equation permits the measurement of the radial velocity of a space vehicle with respect to a source of radiation, provided that λ_1 is known, and $\Delta\lambda$ can be measured. The velocity error δv depends on the accuracy of the measurement of λ_1 and λ_2 and is given by the formula

$$\delta v \doteq \frac{2c\delta\lambda}{\lambda_1}, \tag{2}$$

where $\delta\lambda$ = error in the determination of wavelength. The suitability of Doppler methods of velocity determination therefore depends on the magnitude of $\delta\lambda$ which, in turn, is influenced by the intensity and shape of the spectral lines and the measuring equipment characteristics. As for the lines themselves, the most desirable characteristics are high intensity and good sharpness (narrow width).

CHARACTERISTICS OF SPECTRAL LINES IN THE OPTICAL REGION

Aller[1] has outlined the causes of broadening of spectral lines. The most important of these for our present discussion is the Doppler effect, whereby lines are broadened due to the random kinetic motion of the atoms, the turbulence of large masses of gases in the atmospheres of the heavenly sources, and the axial spin of the source if the light is integrated from all parts of the source. Aller derived an expression for the halfwidth of the line, broadened only by Doppler effects:

$$\Delta\lambda = 7.16 \times 10^{-7}\lambda\sqrt{\frac{T}{\mu}}, \tag{3}$$

where

$\Delta\lambda$ = the halfwidth of the line,
λ = the wavelength of the line,
T = the temperature (°K),
μ = the molecular weight of the radiator (or absorber).

The lines are broader, therefore, for longer wavelengths and higher temperatures, and for the lighter elements.

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* Original manuscript received by the IRE, December 2, 1959. This study has been supported by the USAF, Wright Air Development Center, Dayton, Ohio, under Contract No. AF 33(616)-5898.

† Labs. for Research and Development, The Franklin Institute, Philadelphia, Pa.

[1] L. H. Aller, "Astrophysics," The Ronald Press Co., New York, N. Y., ch. 8; 1953.

The shape of the spectral lines at the center is largely determined by Doppler effects, whereas other causes, e.g., radiation and collision damping, fix the shape at greater distances from the center of the line. Analysis of the Doppler effects shows that even narrow lines have comparatively flat tops. Therefore, for wavelength determination, the sides of the line should be utilized wherever possible.

With regard to intensity, the sun is the only source which provides adequate energy for high-accuracy spectroscopic measurements. The Babcock magnetograph,[2] for example, is able to provide an equivalent velocity resolution of one meter per second in Doppler measurements, using the sun as the source. The radiation received from even the brightest stars, however, is approximately only 1×10^{-10} as intense. Stars differ greatly on the basis of both apparent intensity and spectra. They may be classified according to their spectra which in turn are a function of the star temperature. Table I lists the spectrum classes of the main sequence stars, the associated temperatures and some of the more characteristic features of each class. Each class is further subdivided, as B0, B1, $\cdots$, B9.

By assuming that the sun and the stars radiate as black bodies, the fraction of the total emittance over any given wavelength range can be calculated from the radiation laws

$$W_{bb} = \sigma T^4, \tag{4}$$

(1)

where

W_{bb} = the total radiant emittance of a black body at the temperature T,

T = absolute temperature (°K),

σ = the Stefan-Boltzmann constant;

(2)

$$\frac{dW_{bb}}{\Delta\lambda} = W_\lambda = \frac{c_1 \lambda^{-5}}{e^{c_2/\lambda T} - 1}, \tag{5}$$

where

W_λ = spectral emittance at the wavelength λ over a bandwidth $\Delta\lambda$,

c_1, c_2 = first and second radiation constants.

From this, the spectral irradiance $H_{s\lambda}$ over the wavelength band $\Delta\lambda$ of a source is given by

$$H_{s\lambda} = \frac{W_\lambda}{W_{bb}} \times H_s, \tag{6}$$

where H_s is the total irradiance of the source on the earth.

In the case of the sun, H_s, the solar constant is 0.14 watt/cm², and for a star of zero bolometric magnitude, H_s has been determined to be 2.27×10^{-12} watts/cm².

TABLE I

SPECTRUM CLASSES AND THEIR CHARACTERISTICS

Spectrum Class	Mean Color Temperature	Characteristic Features
0	23,000°K	Faint He lines present.
B0	21,000	He lines intense, reaching a maximum in B2 stars and fading out in B9 stars.
A0	11,000	*H* lines reach a maximum; metal lines begin to appear.
F0	7,300	*H* lines fade out; metal lines, especially Ca (*H* and *K*), increase.
G0	5,900	Metal lines appear in great numbers.
K0	5,280	Metal lines are most prominent; Ca (*H* and *K*) reach a maximum intensity; molecular bands appear.
M0	3,590	Bands of TiO are prominent.

The sun is a G2 star.

The spectral irradiance over a bandwidth of 1 A has been calculated for various wavelengths from the sun and from stars of zero bolometric magnitude and different spectrum classes. These are given in Table II. Included also are the wavelengths of maximum energy calculated by the relationship

$$\lambda_{\max} = (2.8971/T) \times 10^7 \text{ A}. \tag{7}$$

The last column lists the apparent visual magnitudes.

For stars other than those of zero bolometric magnitude, the irradiances may be calculated from the formula

$$m_2 - m_1 = 2.5 \log \frac{L_1}{L_2},$$

where m_2 and m_1 are the visual magnitudes of the unknown and standard star (of zero bolometric magnitude) of the same spectral class, and L_1 and L_2 are the intensities of the unknown and standard stars respectively. Since the unknown star is being compared to a standard star of the same temperature, L_1 and L_2 may represent their respective irradiances at any wavelength. These data for some of the brightest stars appear in Table III.

While there is much general information as to the lines to be found in stellar spectra, such as the excellent group of photographs published by Morgan, Keenan, and Kellman,[3] there is a scarcity of definite photometric data on the line profiles. Hiltner and Williams[4] have published data for eight stars in their "Photometric Atlas of Stellar Spectra." Fig. 1 is a reproduction of a trace for Rigel in the region of the Ca II *H* and *K* lines at 3968 and 3934 A, and of H_γ and H_δ lines at 4340 A and 4102 A. Fig. 2 shows a similar trace for Sirius. The spectra of cooler stars exhibit many lines, as can be

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[2] H. W. Babcock, "The solar magnetograph," *Astrophys. J.*, vol. 118, pp. 387–396; November, 1953.

[3] W. W. Morgan, P. C. Keenan, and E. Kellman, "An Atlas of Stellar Spectra," University of Chicago Press, Chicago, Ill.; 1943.

[4] W. A. Hiltner and R. Williams, "Photometric Atlas of Stellar Spectra," University of Michigan, Ann Arbor, Mich.; 1946.

TABLE II

SPECTRAL IRRADIANCE OF STARS OF ZERO BOLOMETRIC MAGNITUDE (WATTS/CM²/A)

Spectral Class	Temperature °K	$H_{s\lambda}$ λ4000A 10^{-16}	$H_{s\lambda}$ λ5000A 10^{-16}	$H_{s\lambda}$ λ1μ 10^{-16}	$H_{s\lambda}$ λ5μ 10^{-19}	$H_{s\lambda}$ λ10μ 10^{-19}	λ_{max} A	Apparent Visual Magnitudes
B0	21,000	1.66	0.84	0.078	0.167	0.011	1,317	2.8
B5	16,000	2.65	1.46	0.156	0.369	0.024	2,069	1.4
A0	11,000	3.70	2.75	0.381	1.064	0.0726	2,708	0.6
A5	8,700	4.19	3.18	0.681	2.10	0.143	3,408	0.2
F0	7,300	3.90	3.41	0.855	3.47	0.241	3,915	0.0
F5	6,400	3.41	3.36	1.053	5.00	0.352	4,457	0.0
G0	5,900	2.84	3.12	1.172	6.26	0.449	4,910	0.5
G5	5,570	2.51	2.90	1.276	7.19	0.518	5,267	0.1
K0	5,280	2.37	2.88	1.362	8.46	0.610	5,912	0.17
K5	4,550	1.63	2.36	1.59	11.90	0.943	6,898	0.6
M0	3,590	0.696	1.40	1.83	23.49	1.826	8,048	1.2
M5	2,800	0.06	0.36	1.63	4.85	0.405	10,350	2.4
G2(sun)	5,760	1.5×10^{11}	1.9×10^{11}	7.6×10^{10}	4.0×10^{11}	2.9×10^{10}	5,030	−26.7

TABLE III

SPECTRAL IRRADIANCE OF SOME BRIGHT STARS (WATTS/CM²/A)

Star	Class	Visual Magnitudes	$H_{s\lambda}$ λ4000A 10^{-16}	Star	$H_{s\lambda}$ λ5000A 10^{-16}	Star	$H_{s\lambda}$ λ1μ 10^{-16}	Star	$H_{s\lambda}$ λ5μ 10^{-19}	Star	$H_{s\lambda}$ λ10μ 10^{-19}
Sirius	A0	−1.6	28.0	Sirius	21.0	Betelgeuse	3.6	Betelgeuse	41.5	Betelgeuse	3.08
Canopus	F0	−0.9	8.9	Canopus	7.8	Sirius	2.9	Arcturus	8.2	Arcturus	0.6
β Centauri	B1	0.9	8.1	β Centauri	5.1	Canopus	1.9	Sirius	8.1	Sirius	0.6
Vega	A0	0.1	6.7	Vega	4.3	Arcturus	1.3	Canopus	7.9	Canopus	0.55
Rigel	B8	0.3	6.3	Rigel	3.9	Vega	0.6	Vega	1.7	Vega	0.12
Achernar	B5	0.6	5.5	Achernar	3.0	Rigel	0.5	Rigel	1.4	Rigel	0.09
Spica	B2	1.2	4.7	Arcturus	2.8	β Centauri	0.4	Pollux	1.3	Pollux	0.09
Arcturus	K0	0.2	2.3	Spica	2.4	Altair	0.35	Altair	1.1	Altair	0.08
Altair	A5	0.9	2.2	Betelgeuse	2.4	Achernar	0.3	β Centauri	0.9	β Centauri	0.05
Deneb	A2	1.3	1.8	Altair	1.7	Spica	0.23	Achernar	0.8	Achernar	0.05
Fomalhaut	A3	1.3	1.6	Deneb	1.2	Deneb	0.22	Deneb	0.7	Deneb	0.05
Betelgeuse	M2	0.9	0.77	Fomalhaut	1.2	Fomalhaut	0.22	Fomalhaut	0.7	Fomalhaut	0.05
Pollux	K0	1.2	0.37	Pollux	0.45	Pollux	0.21	Spica	0.5	Spica	0.03

seen from Fig. 3 (a) and 3 (b), which are copies of a representative portion of the photometric traces of the spectra of Procyon and Arcturus.

ACCURACY OF VELOCITY DETERMINATION IN THE OPTICAL REGION

As can be seen from Table III, the radiation available from the stars for Doppler measurements is small. An instrument of high resolution and dispersion is necessary to permit accurate measurements, and detectors of great sensitivity are necessary to record small line displacements.

The common technique used in measuring Doppler shift is that of employing two receiving channels separated by a fixed frequency interval and situated on either side of the center of the line to be measured. The outputs of the two channels are compared as the pair is moved across the line, and at the instant a null is obtained (when the outputs of both channels are equal) the center line frequency is deduced as being midway between the two channel frequencies. Any shift in line frequency necessitates a corresponding shift of the two channels in order to reestablish a null. With such a system, it has been shown[5] that, to a good approximation, the change in flux falling on the balanced detector system caused by a displacement $d\lambda$ of an absorption line is given by

$$dL = 2\alpha E_\lambda d\lambda, \tag{8}$$

where

dL = the change in flux,
α = the fraction of radiation absorbed at the center of the line,
E_λ = flux emerging from the spectrograph at λ (without absorption),
$d\lambda$ = the displacement of the line.

The total flux falling on the detectors is

$$L = E_\lambda \Delta\lambda(1 - \alpha/2), \tag{9}$$

where

L = the total flux,
$\Delta\lambda$ = the halfwidth of the line.

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[5] "The Franklin Institute Fourth Quarterly Engineering Report on the Study of Electromagnetic Phenomena for Space Navigation," Philadelphia, Pa., Contract AF 33(616)-5898, Project No. 8(623-5219); June 30, 1959.

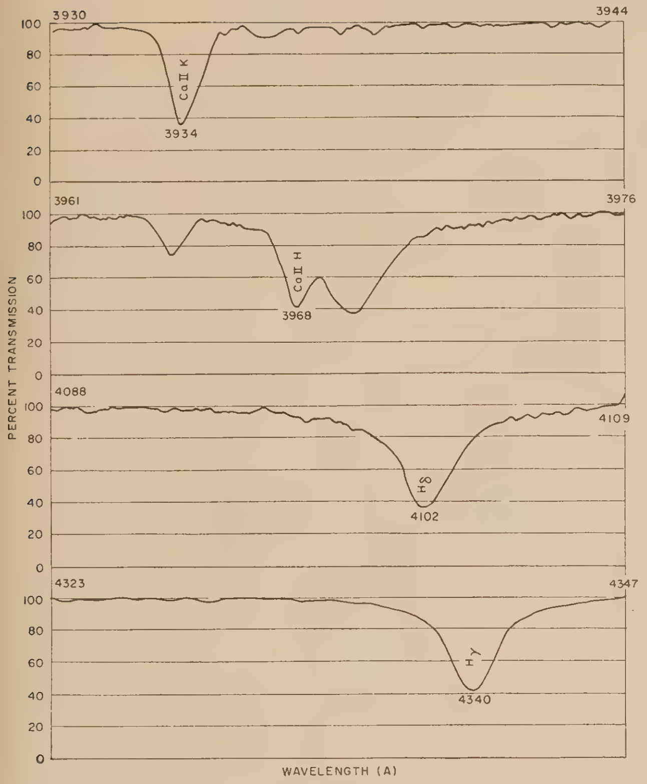


Fig. 1—Photometric traces of spectrum of Rigel.

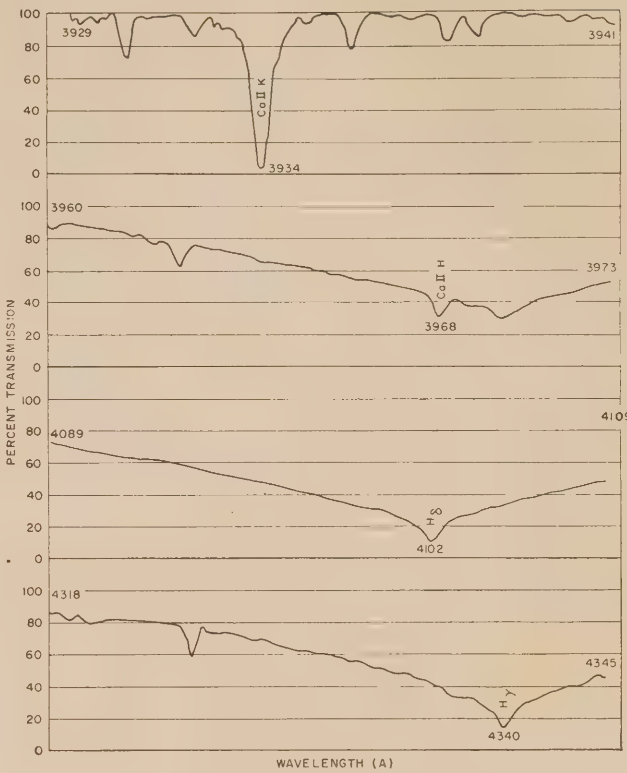
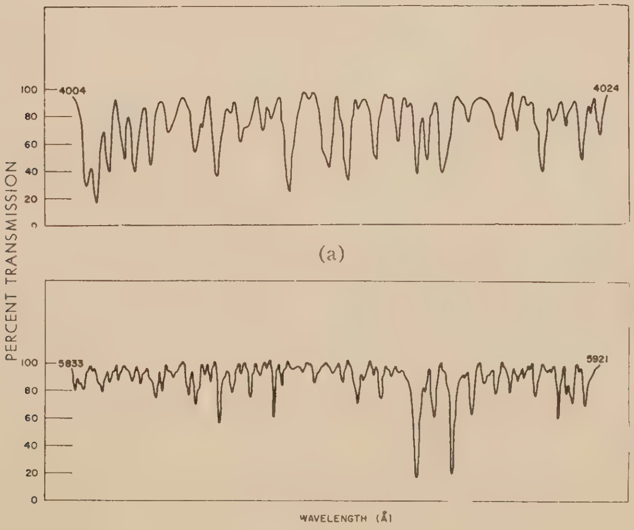


Fig. 2—Photometric traces of spectrum of Sirius.



(a)

(b)

Fig. 3—Photometric traces of stellar spectra.
(a) Procyon. (b) Arcturus.

The ratio of the change in flux to the total flux is therefore

$$\frac{dL}{L} = \frac{2\alpha E_\lambda d\lambda}{E_\lambda \Delta\lambda(1 - \alpha/2)} = \frac{2\alpha d\lambda}{\Delta\lambda(1 - \alpha/2)}. \qquad (10)$$

It is evident from this equation that narrow, strongly absorbing lines are best suited to velocity measurements. The above derivation assumes that the halfwidth of the line and the width of the signal channels are approximately equal.

The equation given below relating the various parameters involved in the detection process has been derived by the workers at the General Precision Laboratory.[6]

$$\sigma(V) = \frac{c}{\lambda}\,\frac{1}{E_\lambda \alpha S}\sqrt{\frac{Ge}{2t}\left[I_D + E_\lambda S\left(W - \frac{\alpha\Delta\lambda}{2}\right)\right]}. \qquad (11)$$

In this equation

$\sigma(V)$ = error in velocity measurements,
c = velocity of light,
λ = wavelength of the light used,
S = spectral sensitivity of the detector tubes,
G = gain of the detector tubes,
e = the charge of an electron,
t = the smoothing time,
I_D = the dark current of the detector tubes,
W = the bandwidth of the signal channel (exit slits of the spectrograph),
$\Delta\lambda$ = halfwidth of the absorption line.

The flux E_λ emerging from the spectrograph system is a function of the irradiance of the source, the area of the collecting telescope, and the attenuation of the optical system. It may be represented by

$$E_\lambda = H_s d\lambda 0 \epsilon, \qquad (12)$$

where

$H_s d\lambda$ = the irradiance of the source,
0 = the area of the telescope collector,
ϵ = the attenuation of the optics.

The errors in the measurement of the velocity $\sigma(V)$ vs the diameter of the collecting telescope were computed by the use of this equation for Sirius and for Rigel, Figs. 4–6, using the parameters indicated in the figures. It may be seen that detectors of the highest quality are essential by comparing Figs. 5 and 6, where computations were made for Rigel using different tube parameters.

SYSTEMS FOR DOPPLER MEASUREMENTS

While it is not our present aim to propose a specific design for an instrument, certain features can be outlined and suggestions made on the basis of an examina-

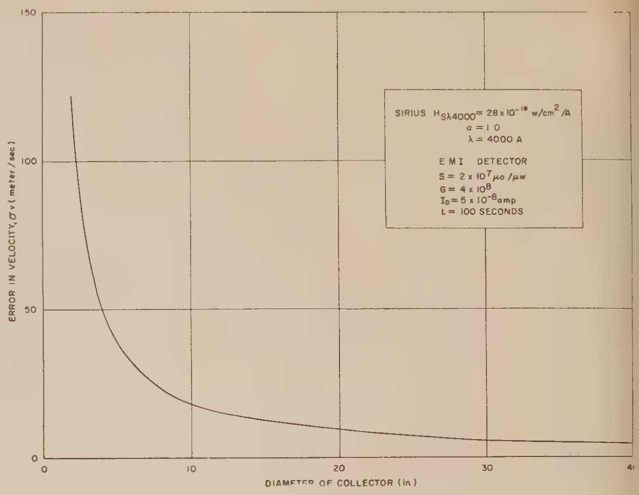


Fig. 4—Variation of errors in velocity measurements with diameter of collector

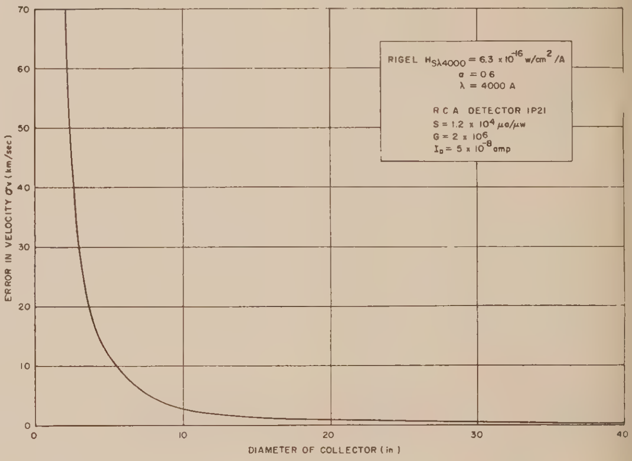


Fig. 5—Variation of errors in velocity measurements with diameter of collector

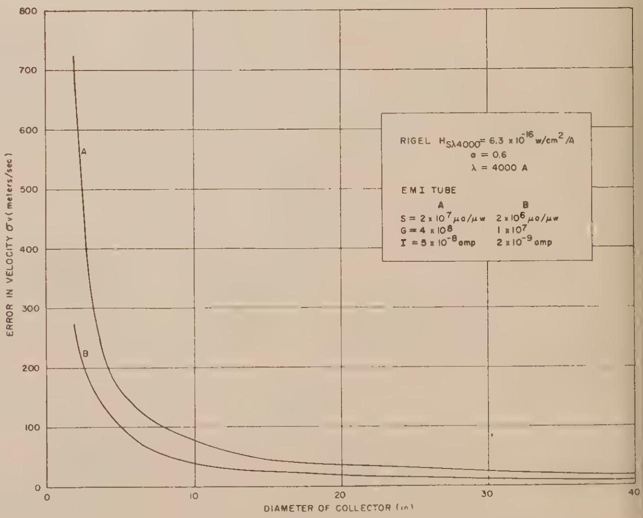


Fig. 6—Variation of errors in velocity measurements with diameter of collector.

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[6] "Interim Engineering Report on the Study of Electromagnetic Phenomena for Space Navigation," General Precision Laboratory Inc., Pleasantville, N. Y., Contract No. AF 33(616)-5487; January, 1959.

tion of the preceding results. Such an instrument should have the following components:

1) A collecting telescope. From Figs. 4–6, it can be seen that little is to be gained by increasing the diameter of the collector above 8 or 10 inches which would therefore be a practical compromise between efficiency and weight.

2) The spectrograph. In order to attain the necessary dispersion and resolution an echelle-prism system might be used to advantage, since such a system combines high dispersion and resolution with efficiency.

3) A slit system in the focal plane of the spectrograph. This slit system would be so constructed as to divide the radiation from a line, permitting the flux from each half to fall on a detector. The output from the two detectors would be balanced at zero velocity.

4) Detectors. As pointed out above, the detectors must be of the highest quality.

Because of the low signal level, it is interesting to examine the effect of using more than one line by employing more than one slit in the detector assembly. The total change in the flux for *n* lines in the same spectral range would then be *n* times the average change for one line or

$$dL = 2n\bar{\alpha}\bar{E}_\lambda\overline{d\lambda},$$

and (12) becomes

$$\sigma(V) = \left(\frac{C}{\bar{\lambda}n\bar{\alpha}\bar{E}_\lambda S}\right) \cdot \sqrt{\frac{Ge}{2t}\left[I_D + n\bar{E}_\lambda S\left(W - \frac{\bar{\alpha}\Delta\lambda}{2}\right)\right]}. \qquad (13)$$

For any given star, E_λ and $d\lambda$ will remain essentially constant over a small wavelength range, but α may vary from 1 to 0. Fig. 7 shows the effect of varying α for $H_{s\lambda} = 1 \times 10^{-16}$ watts/cm² A, for different values of *n* (heavy curves). The other parameters are as indicated in the figure. It can be seen that as α decreases, the velocity error $\sigma(V)$ increases rapidly with a limiting value of ∞ when $\alpha = 0$. Thus it is necessary to use only those lines having large values of α, and weakly absorbing lines must be excluded. To illustrate this, assume that the value of α remains constant ($\alpha = 0.9$). If one slit is used, $\sigma(V) = 153$ meters per second as shown by × on the appropriate curve. If 2 slits are used, $\sigma(V) = 96$ meters per second. Similarly, for $n = 5$, 10, 20, and 30 slits, the values of $\sigma(V)$ are 56, 37, 25, and 20 meters per second, as shown by the points marked × in the figure.

But if α is also varied when several slits are used, the velocity errors may be increased. Assume the following values of α for the various values of *n*:

n	*nH*$_s$ (*watt/cm² A*)	$\bar{\alpha}$	$\sigma(V)$ (*meters per second*)
1	1×10^{-16}	0.9	153
2	2×10^{-16}	0.8	112
5	5×10^{-16}	0.6	90
10	10×10^{-16}	0.4	98
20	20×10^{-16}	0.2	144

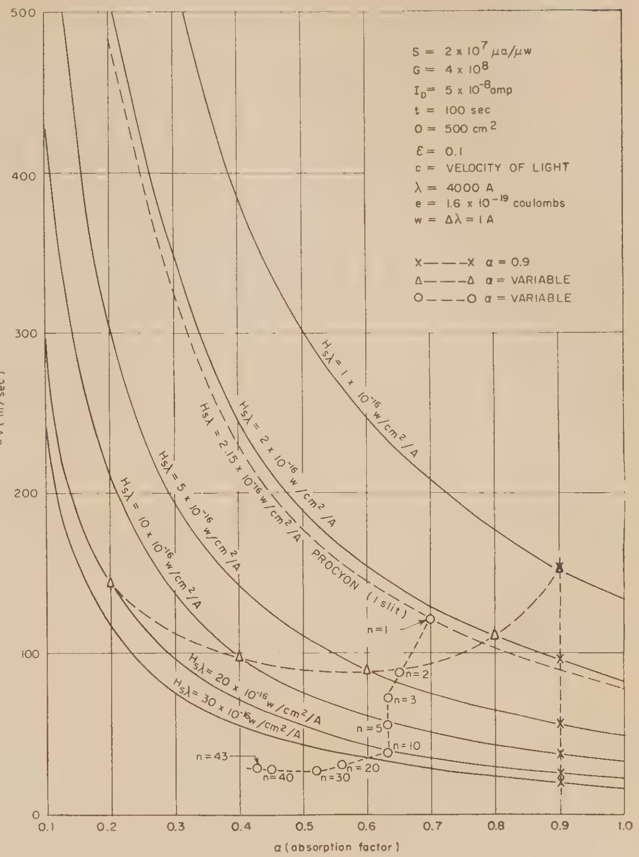

Fig. 7—Velocity errors vs absorption factor for various levels of stellar irradiance.

These points appear in Fig. 7 as △··· △. It is evident that for the values of α chosen for this illustration, the optimum number of lines is five or six. If more than this number are used, the velocity error increases.

This type of calculation was also performed using the spectrum of Procyon from 3990 A to 4020 A, part of which is reproduced in Fig. 3(a). It was assumed that the narrowest and most absorptive line would be chosen when only one slit is used. In this case, $\alpha = 0.7$ and $\sigma(V)$ is 121 meters per second. This point is ○$n = 1$ on the curve for $H_{s\lambda} = 2.15 \times 10^{-16}$ which is the value in watt /cm²/A of the irradiance of Procyon at $\lambda = 4000$ A. For the next most absorptive line, $\alpha = 0.6$, reducing the average of α to 0.65. Similarly, the average $\bar{\alpha}$ was taken for the 43 lines in the spectral range under consideration and the velocity errors were calculated. These points appear in Fig. 7 as ○··· ○. In this case, little is to be gained from the use of more than ten lines.

THE HYDROGEN 21-CM LINE

The degree to which the hydrogen line may be employed in determining the velocity of a space vehicle is also dependent upon the intensity of the line, its sharpness, and the angular extent and location of the sources. Most of the lines found to date are of rather complex structure due to thermal motions and other turbulence within the clouds, and also to differences in radial velocity of the various clouds along the line of sight. In emission, the sharper lines range in width from 120 kc to 170 kc, corresponding to a velocity range of 24 km/sec to 34 km/sec. Quite often, the lines are much broader, and some widths are found ranging from 800 kc (160 km/sec) to 1 mc (200 km/sec). Absorption lines, where found, have characteristics much more suitable for Doppler measurement. Fig. 8 (see Hagen, *et al.*[7]) shows the line configuration obtained when viewing the Cassiopeia A source. The absorption lines exhibit widths at the half-power points of only 20 to 25 kc. The much increased sharpness of lines in absorption is attributed to the greater angular resolution obtained through the use of discrete sources. The angular size of the Cassiopeia A source is estimated at only 6 minutes of arc which would correspond to the beamwidth of a 500-foot antenna. This equivalent small beamwidth restricts the amount of hydrogen cloud viewed, so that smaller random velocity and Doppler shifts due to cloud motion are included.

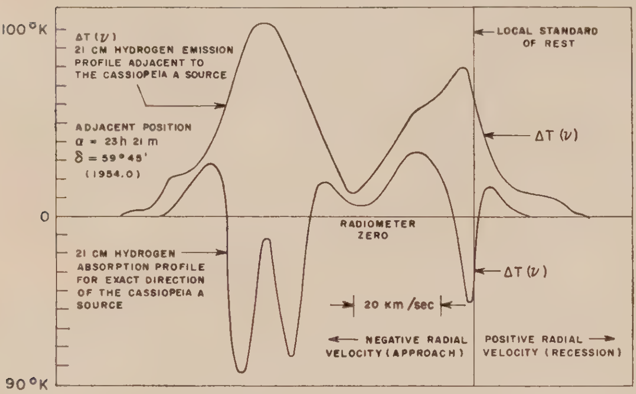

Fig. 8—Profile type of absorption measurement. (Two 21-cm hydrogen line profiles are shown, one for the direction of the Cassiopeia A source and one for a comparison position taken approximately 1° away.) (See Hagen, *et al.*[7])

The energy available from 21-cm sources is also small, necessitating the use of large antennas and highly stable radiometer-type equipment with long integration times, in order that the signal may be distinguished from the noise background. Brighter sources which have been discovered to date provide peak antenna temperatures in the neighborhood of 100°K. Most of the sources, however, provide energy levels much less than this. In order to provide a signal-to-noise ratio of at least 10.0, when the antenna temperature is 80°K the receiving equipment must be so designed that the equivalent noise temperature is below 8.0°K. Another factor entering into the receiver design is the band-pass. It has been determined that in order to provide good definition, the band-pass should be no larger than 5 kc. However, this is subject to some variation for our purposes, as we shall see later. Therefore, according to the definition of antenna temperature as Ta,

$$Ta = \frac{P}{k\Delta f} \qquad (14)$$

where

P = power received by antenna,
k = Boltzmann's constant,
Δf = receiver band-pass.

If $\Delta f = 5$ kc, the input power corresponding to an antenna temperature of 80°K is only 5.5×10^{-18} watts, and the noise level for good measurement capability should not exceed approximately 10^{-19} watts.

The ordinary form of the radiometer equation postulated by Dicke[8] for the rms fluctuation in antenna temperature when looking at a radio source is

$$\Delta T = [(F-1)T_0 + T_A]\pi/2 \sqrt{\frac{1}{B\tau}} \qquad (15)$$

where

F = noise figure for signal and image bands,
B = predetection bandwidth,
τ = integration time,
T_0 = ambient temperature,
T_A = antenna temperature of radio source.

Noise figures of 8 db ($F = 6.3$) are readily realized, giving a receiver noise temperature $(F-1)T_0$ of 1550°K. Using a source antenna temperature of 80°K, and a 5-kc band-pass, the above equation shows that an integration time of 100 seconds results in a detectability ($S/N = 1$) of 3.6°K. Recent reports on the successful application of maser preamplifiers at 21 cm indicate that receiver noise temperatures at least as low as 50°K are realizable. In this case, a band-pass of 5 kc and an integration time of 100 seconds would permit a detectability of 0.3°K, showing an improvement of better than 10:1.

These figures on sensitivity can now be applied to the problem of determining the accuracy with which line shift, and hence velocity, can be measured. The method of detecting line position will be assumed to employ detection channels on either side of the line being measured, similar to the technique described for optical frequencies. Work has been done on optimum channel widths and separation to provide best sensitivity.[9] It will suffice to point out briefly that the bandwidth of the filters and the separation between them should be of the order of magnitude of the halfwidth of the line. Under these conditions, it can readily be shown that for small displacements Δf of the line, having a depth T expressed in units of antenna temperature, the power in one channel will increase approximately by an amount $kT\Delta f$, and the power in the second channel will decrease by a like amount, giving a total change in input power of $2kT\Delta f$. This will cause an equivalent temperature change at the input of the receiver of

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[7] J. P. Hagen, S. E. Lilley, and E. F. McClain, "Absorption of 21 cm radiation by interstellar hydrogen," *Astrophys. J.*, vol. 122, pp. 361–375; November, 1955. See p. 369.

[8] R. H. Dicke, "The measurement of thermal radiation at microwave frequencies," *Rev. Sci. Instr.*, vol. 17, pp. 268–275; July, 1946.

[9] P. M. Schultheiss, C. A. Wogrin, and F. Sweig, "Time frequency measurement of narrow band random signals in the presence of wide band noise," *J. Appl. Phys.*, vol. 25, pp. 1205–1036; August, 1954.

$$\Delta T = \frac{2kT\Delta f}{kB} = \frac{2T\Delta f}{B}, \tag{16}$$

where B = the receiver band-pass.

Now it has been shown that with an integration time of 100 seconds, a detectability of 3.6°K is well within the capability of an ordinary radiometer, and with a maser preamplifier, detectabilities of at least 0.3°K are possible. The band-pass of the receiver should be adjusted as nearly as possible to correspond to the halfwidth of the line being measured. Referring once again to Fig. 8 it is found that this value for the Cassiopeia absorption line is approximately 4 km/sec which at the frequency of 1421 mc corresponds to 19 kc. T has the value of 80. Substituting these values in (16) and noting that increasing the receiver band-pass to 19 kc changes the detectability from 3.6°K to 1.8°K, we find an uncertainty in the measurement of line position of 45 meters per second (148 feet per second), and with a maser ($\Delta T = 0.15°$K), an uncertainty of only 3.7 meters per second (12.2 feet per second). In measuring velocity by means of Doppler shift, the difference between the shifted and the unshifted line must be determined so that the uncertainty in velocity measurement should be twice the above values or 90 meters per second (296 feet per second) and 7.4 meters per second (24.4 feet per second), respectively.

At the present time, the hydrogen line at 21 cm is still the only line that has been detected in interstellar space by radio techniques. A number of other lines have been predicted, however. Data thus far gathered indicate that the diatomic molecules, especially hydrides, are the important molecules of interstellar space. Radiation from these molecules has been predicted throughout the millimeter wave region, and far infrared. Unfortunately, the detection of millmeter lines is very difficult compared with the 21-cm line because of equipment limitations, absorption in the terrestrial atmosphere, the reduced abundance of the molecules, the reduced-state temperature of the molecular energy levels defining the millimeter transitions and the lack of bright point sources in the sky at these frequencies. Improved equipment and satellites are certain to overcome the first two objections. Hence, the detection of these lines is not considered hopeless. At present, however, an appraisal of their value to navigational problems in space is impossible. It does appear fairly certain that, because of the rarity of these lines, the intensity of radiation received even in outer space at these wavelengths will be far less than that due to hydrogen, thereby raising considerably the performance level required of the equipment. Cosmic rays have also been examined, but have been found not to hold any immediate promise for space navigation, primarily because no discrete sources are available, and no discrete line spectra exist for the measurement of frequency shifts.

SOLAR RADIATION AND SOLAR DIAMETER

Solar radiation has been suggested as a means of determining the distance of a space vehicle from the sun. This information coupled with angle measurements on the sun and planets would permit the determination of vehicle position in space. Press has estimated that the total uncertainty in measuring the earth-sun distance with such a scheme would be 10,000 miles.[10] For velocity, our primary interest would be in the change in radiation power with time. Therefore, the absolute magnitude of solar radiation is unimportant. Constancy of radiation with time, on the other hand, is extremely important.

Power radiated from the sun and intercepted by a detector may be approximated from the black body law as

$$P = \frac{\sigma A_s A_D T^4}{\pi D^2}, \tag{17}$$

where

σ = Stephan-Boltzmann constant,
A_s = area of sun,
A_D = area of detector,
T = temperature of the sun,
D = distance from the sun,

and the rate of change of this power with time is given by

$$\frac{dP}{dD} = \frac{2\sigma A_s A_D T^4}{\pi D^3}. \tag{18}$$

Radial velocity with respect to the sun is therefore given by

$$V = \frac{\Delta P}{\Delta t} \times \frac{1}{\frac{dP}{dD}}. \tag{19}$$

Table IV lists the radiation power and rate of change with distance for the neighborhoods of Earth, Venus, and Mars.

TABLE IV
(AREA OF DETECTOR = 1 CM²)

	Earth	Venus	Mars
P (watts	0.14	0.18	0.118
$\frac{dP}{dD}\left(\frac{\text{watts}}{\text{meter}}\right)$	1.74×10^{-12}	2.41×10^{-12}	1.58×10^{-12}

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[10] S. Press, "An application of solar radiation to space navigation," *Aero-Space Engrg.*, vol. 17, pp. 51–54; November, 1958.

The procedure in making measurements of radial velocity with respect to the sun would be that of taking distance measurements at two different times, and dividing the distance change by the time interval. Accordingly,

$$V = \frac{D_1 - D_2}{T_1 - T_2}. \tag{20}$$

Assuming that errors exist in both the time and distance measurements, the resulting error in velocity is given by

$$\Delta V = \frac{\Delta D_1}{T_1 - T_2} + \frac{\Delta D_2}{T_1 - T_2} + \frac{(D_1 - D_2)\Delta T_1}{(T_1 - T_2)^2} + \frac{(D_1 - D_2)\Delta T_2}{(T_1 - T_2)^2},$$

and, assuming that $\Delta D_1 = \Delta D_2$, and $\Delta T_1 = \Delta T_2$,

$$\Delta V = \frac{2\Delta D}{T_1 - T_2} + \frac{2\Delta T(D_1 - D_2)}{(T_1 - T_2)^2}. \tag{21}$$

It becomes apparent that the velocity error is dependent upon the time interval between readings. If the velocity may be considered as a slowly changing quantity so that readings may be taken over intervals which are large compared with the accuracy of measurement, the error may be controlled. For a time interval of 100 seconds, and a photocell detectivity of 10^{-6} watts (6×10^5 meters), the velocity uncertainty at the distance of the earth from the sun would become approximately

$$\Delta V = \frac{2 \times 6 \times 10^5}{100} = 12 \text{ km/sec } (39{,}000 \text{ feet/second}).$$

Turning now to the problem of measuring distance and velocity through angular measurements of the sun's diameter, the distance error for a given error in angular measurement is given by

$$\Delta D = \frac{d\Delta\alpha}{\alpha^2}, \tag{22}$$

where

d = diameter of the sun,

α = angular diameter of the sun in radians.

Taking the earth-measured angular diameter of the sun as 0.0093 radian and the diameter as 13.9×10^8 meters, the error in the measurement of the earth-sun distance for each second error in angular measurement is

$$\Delta D = \frac{13.9 \times 10^8 \times \pi}{(0.0093)^2 \times 3600 \times 180}$$
$$= 7.8 \times 10^7 \text{ meters } (48{,}500 \text{ miles}).$$

Assuming an angular error as 0.1 second (which is realistic in view of present equipment),

$$\Delta D = 7.8 \times 10^6 \text{ meters}$$

and the error in determining radial velocity with a 100-second interval between readings would be given as before:

$$\Delta V = \frac{2\Delta D}{T_1 - T_2} = \frac{2 \times 7.8 \times 10^6}{100}$$
$$= 156 \text{ km/sec } (510{,}000 \text{ feet/second}).$$

CONCLUSIONS

Reviewing the results of the past study, a number of conclusions can be drawn. First of all, cosmic rays do not appear feasible as an aid to space navigation, primarily because no discrete sources of radiation are available and no discrete line spectra exist. Studies of other radiation in the visible and radio regions reveal that the primary difficulty is one of extremely low signal levels. To illustrate, the brightness temperatures of 21-cm sources range from 0° to 100°K. Viewing an 80°K source with a 50-foot antenna and a receiver band-pass of 5 kc, one would have a signal level of only 5.5×10^{-18} watts. At optical wavelengths, the power available from the brightest stars in the region of 5000 A is approximately 1×10^{-12} watts/A if viewed through a 10-inch telescope. The sun, of course, is an exception. When viewed under the same conditions, a quite adequate power level of 9.5×10^{-3} watts/A is obtained.

Except for the sun, then, it is obvious that in measuring Doppler shifts with such low-level signals, special detection equipment with high sensitivity and long time constant is required in order to distinguish the signal from the noise. If the assumption is made that the detection limit occurs when the signal is equal to the noise, the capabilities of various systems can be compared as in Table V where the noise level is expressed in

TABLE V
SYSTEM COMPARISON

Source	System	Integration Time	Noise Level
Optical Doppler			
Sun	Babcock Magnetograph	100 seconds	3 feet/second
Sirius	10-inch Telescope Detection System Similar to Magnetograph	100 seconds	60 feet/second
Radio Doppler (21 cm)			
Cassiopeia A	Radiometer 50-foot Antenna	100 seconds	148 feet/second
Cassiopeia A	50-foot Antenna with Maser	100 seconds	12.2 feet/second
Other			
Sun	Total Radiation	100 seconds	39,000 feet/second
Sun	Diameter Measurement	100 seconds	510,000 feet/second

terms of equivalent velocity in feet per second. This noise level varies inversely as the square root of the output integration time for the radio and optical systems. Consequently 100 seconds was chosen as a convenient value upon which to base our comparison. In instances where longer times can be tolerated, an equivalent improvement in detectability may be expected up to the point where equipment instabilities become a problem. It should be pointed out that where velocity is derived from measurements of total solar radiation or solar diameter, the error varies inversely as the time interval between measurements. So-called "integration time" has therefore a special connotation in these cases.

Taking into account the number of available sources, the energy available, and the complexity and size of equipment, it appears that natural radiation in the optical range of frequency holds the greatest promise for early successful application to space navigation. Excellent detectors are available in this range, but low signal level still persists as a major problem.

The Optimization of Astronautical Vehicle Detection Systems Through the Application of Search Theory*

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Summary—A generalized theory of detection system performance is developed and applied to the analysis of collision warning and the optimal allocation of search effort for astronautical vehicles. The kinematic basis of the relative frequency of intercepts with randomly moving particles is presented. The pronounced variation in warning system effectiveness if the possible contact space is uniformly scanned is displayed by investigating the functional behavior of the weighted mean acquisition range and cumulative probability of detection by some minimal detection barrier in the hypervelocity closure rate, low signal amplitude operational environment. Fixing the search system frame time, it is shown that the probability of acquiring a closing particle by some critical range determined by the system response delay may be made independent of the bearing angle of the relative approach path by choosing search system dwell times that are proportional to the second or fourth power of the mean anticipated closure rate, the exponent being dependent upon whether the sensor is active or passive.

The rational choice of the frame time is investigated in terms of the information rate out of the sensor and the requirements of the decision-making apparatus. The latter is assumed to be an unsaturated, bandwidth and memory limited data processing subsystem. The probability of track retention and the variance of the best estimate of the contact-bearing angle are related to the cumulative probability of detection. It is shown that the required system reaction times are in conflict with the optimal detection system information rates.

The very important case of contacts between astronauts and other objects independently moving on trajectories defined by a generalized central force field is separately considered. It is shown that while a true collision contact is only possible in trivial cases, as viewed by the astronautical vehicle the relative terminal approach trajectory of the particle is essentially confined to a surface defined by reasonable navigational system outputs. The confinement of the search to this restricted region of contacts makes the problem of detection in such an unfavorable environment far more amenable to solution than is possible with omnidirectional coverage.

I. INTRODUCTION

THE obvious stringent weight and space restrictions which obtain in the design development of conventional airborne detection systems are necessarily accentuated if the equipments are intended for astronautical vehicles. Unfortunately, while the means of solution to problems such as those of anticollision warning decline with the possibility of implementing effective sensors, the situation with regard to astronauts is further aggravated by the hypervelocity closure rates and minuscule size of meteors that will frequently be the subjects of detection. Since sensor improvements offer little in the way of adequate enhancement of the signal levels themselves, alternate solutions in terms of the extraction of more information from such signals as may be present, or an increase in the efficiency of the

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* Original manuscript received by the IRE, December 2, 1959.

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detection process through optimal allocation of the search effort, must be sought. This paper is concerned with the latter.

To this end, statistical models which are descriptive of most cases of interest, or at least those that are amenable to general analysis, are investigated. As an approximation to the kinematic environment created by sporadic meteors, rectilinear randomly-oriented motion of observer and targets is assumed. It is reasonable to expend the greatest search over those regions of the relative observer space that are the most likely sources of contacts. The question as to how this is best accomplished will be examined at length with the aid of the first statistical model, and an optimal scan program which can be computer-ordered through operation upon navigation system inputs will be derived.

The preceding model is of utility in discussing search during near-terrestrial powered flight and, indeed, appears to provide a meaningful description of the probability density of contacts for conventional vehicles. Representative problems for the latter, to which much of what is to follow is applicable, are the provision of anticollision warning, or the determination of the random target search to be performed by an interceptor in the absence of adequate ground control. However, for reasons of fuel economy, the overwhelmingly greater portion of any space flight must be unpowered and would tend to involve trajectories that are largely described by the kinematics of motion in an isolated central force field. Accordingly, the purely random distribution is later discarded and the nature of contacts between objects that are randomly distributed in space, but whose motion reflects the bias introduced by a communal gravitational field, is investigated.

The issue of anticollision warning has been touched upon above. The density of objects of other than natural origin is now vanishingly small, and undoubtedly will remain so for any foreseeable future. Beyond this, there is an understandable diversity of opinion regarding the frequency and magnitude of the danger of contacts with meteors. Tabulations of earth impacts markedly favor the extremely small particles and suggest, in highly qualitative, generalized terms, that impacts of astronautical vehicles with particles of sufficient size to be catastrophic should be comparatively rare. However, the extent of the commitment of the national industrial potential and human resources to any space exploration enterprise is such as to motivate against the admission of elements of chance. In brief, no rationale is needed at this time for the theoretic consideration of the warning problem in a study devoid of commentary upon specific sensor equipments, or the various courses of action that suggest themselves should such warning be accomplished. Indeed, the feasibility, or even desirability, of responses such as an evasive perturbation of the trajectory of the astronaut must remain unexplored.

II. The Statistics of Particle Distribution and Detector Performance

A. The Density of Contacts as a Function of Bearing Angle

The distances involved are so vast that, over the more modest detection ranges attainable by any sensor that can be envisioned for such application, and the moderate sampling times that would obtain, observable motions will be effectively linear. Further, at least for particles originating in our solar system, their velocities will tend to span some reasonably narrow spectrum of values in a given region of space. Accordingly, it is not unreasonable to construct the required statistical model upon the hypothesis of rectilinear motion of all objects under consideration, and to assign to the particles some mean representative velocity. The latter is not a necessary restriction and, should it later prove possible to assign some probability density function to the velocities that may obtain, the results could be appropriately modified to yield a joint density function of the velocity and the bearing angle β. The phrase "bearing angle" is used in this paper to indicate the angle described by the longitudinal axis of the vehicle and the radial line from the observer to the point in space in question, and measured aft from the positive sense of the velocity vector. In particular, it is not intended to infer thereby that planar motions alone are under consideration.

The mean number of collision contacts to be made along a given bearing line, or rather in a solid angular cone of apex angle $\delta\beta$, is readily shown to be proportional to the closure rate at β. To demonstrate this, we consider a sphere of contacts of arbitrary radius ρ, and note that no particle of a given heading angle can enter unless its relative velocity vector $\boldsymbol{V}$ is so oriented as to point in toward the sphere. That is, the angle between the negative of $\boldsymbol{V}$ and the unit radial vector $\boldsymbol{n}$ must be acute. To a first-order differential approximation, all contacts made in some unit time interval must lie within the relative space volume $(-\boldsymbol{V}\cdot\boldsymbol{n})\rho^2\delta\beta$ which is swept by the moving observer. The required mean number is found by multiplying the preceding expression by the product of the space density of particles and the probability density of the heading angle in question, both of which are constant by virtue of the assumption of randomness. If, in particular, the particle is on a collision course, the normal and reversed relative velocity vectors are coincident and the scalar product is reduced to $|\boldsymbol{V}|$, which was to be shown. It should be noted that the resultant expression is functionally dependent upon β only to the extent that the closure rate is dependent. Koopman [1] extensively discusses the above for planar motion and develops the kinematic basis of detection more fully than is required here.

Certain nonquantitative observations can be made at this time to clarify the intent and structure of the subsequent discussion. It will be shown presently that, all else being equal, the cumulative probability of detection by some minimal admissible range declines very markedly with closure rate. Accordingly, the relative velocity, and therefore the distribution of the search effort, figure prominently. From the above, performance is poorest where it is needed most by virtue of the distribution of the mean density of contacts, unless the allocation of detector dwell is optimized in some sense. To this end, a statistical model of detector performance will now be developed.

B. The Analytical Model of an Idealized Detector and System Optimization

In the brief investigation which follows, no appraisal will be made of such considerations as the significance of the total information content of a sequence of signals. Techniques of noise discrimination through kinematic analysis of the implied motion of a signal source over some sampling interval are representative of such refinements. However, highly sophisticated data processing equipments involving extensive system memory and computer bandwidth would appear to be largely precluded from application in astronautical vehicles. Accordingly, the detection criteria assumed here consist of, at most, a redundancy counter or its equivalent.

Empirically derived data and theoretic analyses suggest that even in the absence of the scintillation induced by a physically dense propagating medium, the input signal power is Rayleigh distributed. That is, the probability density of the scan-to-scan fluctuation is $\overline{S}^{-1}\exp(-S/\overline{S})$, S and $\overline{S}$ denoting, respectively, the instantaneous and mean received signal powers. The dwell time of the scanner will necessarily be so brief in this instance that a high order of signal correlation over that interval may be assumed, in contrast with the individual interrogations which may be regarded as statistically independent trials. Integrating the density function from some threshold S_m to the point at infinity, the single-glimpse probability, exclusive of later information losses, is found to be of the form $\exp(-S_m/\overline{S})$.

The preceding material, as well as the analysis set forth in this section, has been discussed far more extensively in Potter [2], which also investigates the issue of the performance degradation caused by data-handling subsystem limitations that lead to information loss. Though not discussed here, unavoidable restrictions upon computer sophistication must degrade the system performance.

Let the cumulative probability of detection P at range R be required. Writing the single glimpse probability at the λth interrogation as $\psi\equiv\psi[R+\delta+(n-\lambda)Vt]$, where V is the relative range rate, t is the search period, the time interval between successive samples of a given subsector of the relative space, and δ is a small range increment which, physically interpreted, reflects the fact that the last scan may, with equiprobility, occur anywhere within the interval

$$(R,\ Vt+R),\qquad P = 1-\prod_{\lambda=1}^{n}(1-\psi_\lambda),$$

or

$$\ln(1-P)=\sum_{\lambda=1}^{n}\ln(1-\psi_\lambda). \tag{1}$$

The introduction of δ will now be seen to be a device to effect the transition from a discrete to a continuous functional representation since the expected value of $\ln(1-P)$ is its mean with respect to δ taken over the half-open interval over which δ is defined. It may be shown through application of the mean value theorem [2] that if, as is the case in this instance, the sampling rate is high the asymptotic relationship $\overline{\ln(1-P)}\approx\ln(1-\overline{P})$ obtains. As used here, the bar superscript designates a weighted mean value. Assuming, then, the validity of the preceding inferred asymptotic behavior,

$$\begin{aligned}\ln(1-\overline{P})&\\ &=\frac{1}{Vt}\sum_{\lambda=1}^{n}\int_{0}^{Vt}\ln\{1-\psi[R+\delta+(n-\lambda)Vt)]\}\partial\delta\\ &=\frac{1}{Vt}\sum_{\lambda=1}^{n}\int_{R+(n-\lambda)Vt}^{R+(n-\lambda+1)Vt}\ln[1-\psi(\rho)]d\rho\end{aligned} \tag{2}$$

or, discarding the bar notation and accomplishing the indicated summation,

$$\begin{aligned}P&=1-\exp\left[\frac{1}{Vt}\int_{R}^{R+nVt}\ln(1-\psi(\rho))d\rho\right]\\ &=1-\exp\left[\frac{1}{Vt}\left(\int_{R}^{\infty}-\int_{R+nVt}^{\infty}\right)\ln(1-\psi(\rho))d\rho\right]\\ &=1-(1-P_R)/(1-P_{R+nVt}),\end{aligned} \tag{3}$$

where P_R, P_{R+nVt} denote cumulative detection probabilities for search from the point at infinity to the ranges indicated in the subscripts. Since nVt, the relative range traversed during the detection process, is large, P_{R+nVt} is necessarily small with respect to P and P_R, so that one must have $P\approx P_R$.

Adopting the latter approximation, one may now conveniently particularize the resultant general expression to the case of Rayleigh signal power densities. Writing $S_m/\overline{S}=\alpha\rho^\nu$, where ν is 2 or 4 according to whether the sensor is passive or active, α is a parameter that is functionally dependent upon detector and particle characteristics, and ρ is their instantaneous relative range,

$$
\begin{aligned}
P &= 1 - \exp\left[\frac{1}{Vt}\int_R^\infty \ln\left(1 - e^{-\alpha\rho^\nu}\right)d\rho\right] \\
&= 1 - \exp\left[-\frac{R}{Vt}\left\{\frac{1}{R\alpha^{1/\nu}}\int_{R\alpha^{1/\nu}}^\infty \ln\left(1 - e^{-\rho^\nu}\right)^{-1}d\rho\right\}\right] \\
&= 1 - \exp\left[-\frac{R}{Vt}N(x)\right], \qquad (4)
\end{aligned}
$$

where $x = R\alpha^{1/\nu}$, and

$$N(x) = \frac{1}{x}\int_x^\infty \ln\left(1 - e^{-\rho^\nu}\right)^{-1}d\rho. \qquad (5)$$

Eq. (4) may be cast into a somewhat more convenient form which relates the single glimpse and cumulative detection probabilities at some specified range to one another by noting that, for Rayleigh signals, if ψ_R denotes the single glimpse probability at range R, at any other range ρ

$$\psi(\rho) = \psi_R^{(\rho/R)^\nu} = \exp\left[-\rho^\nu(\ln\psi_R^{-1})/R^\nu\right].$$

Accordingly,

$$\alpha = (\ln\psi_R^{-1})/R^\nu,$$

and

$$P = 1 - \exp\left[-\frac{R}{Vt}N(\ln^{1/\nu}\psi_R^{-1})\right]. \qquad (6)$$

Certain observations regarding the choice of scan rates in automatic tracking systems may now be made. Detection is generally followed by at least a brief interval of tracking which may even be integral with the detection process if the decision as to the reality of a contact is predicated upon whether or not its apparent trajectory is erratic. At least in anticollision systems, trajectory analysis is necessarily inherent to the detection process, since contacts of interest are characterized by consistent relative closure. However, the optimization of the sampling rate to yield the greatest attainable cumulative probability of detection in the classical sense, the assurance of a recognizable signal by some specified relative range, will be seen to be at wide variance with the sampling rates indicated by tracking considerations alone. The latter will now be discussed, while optimization of the cumulative detection probability will be deferred to a subsequent portion of this paper.

The admissible prediction time, the interval over which the implied track of an object is projected between successive scans or attempts at correlation, is necessarily limited in tracking systems of the type that would be appropriate for inclusion in an astronautical vehicle. The sophistication of the scan-to-scan correlation process and, in turn, computer bandwidth, grows with the prediction interval, since the region of uncertainty or envelope of potential positions of the contact is a monotone increasing function of the time between successive signals. Accordingly, the expected number of detections relating to a particular contact per unit period of time provides a measure of performance in the large class of systems in which the likelihood of retention of track and the quality of the data processing subsystem output are critically dependent upon the density of the sequence of available samples.

In what is to follow, T denotes the time interval of interest, while the performance of the detector at the given range is defined by the single glimpse probability ψ_R, attained with a scan rate such that successive interrogations occur at intervals t. If, through variation of the scan rate, this latter quantity assumes the value t', then, if the mean signal to root-mean-square noise voltage ratio of the integrator output is taken as proportional to $\sqrt{t'}$, n, the expected number of successful interrogations of the contact may be approximated by $T/t'\,\psi^{t/t'}$. As is apparent, the validity of the preceding expression is contingent upon an interrogation rate that is sufficiently high to insure that the change in the observer-contact relative geometry is inappreciable over the total sampling time.

The first and second derivatives of $n(t')$ with respect to t' may be exhibited in the form

$$
\begin{aligned}
\frac{\partial n}{\partial t'} &= -\frac{T}{t'^2}\psi^{t/t'}\ln\left(\psi^{t/t'}e\right), \\
\frac{\partial^2 n}{\partial t'^2} &= -\frac{1}{t'}\frac{\partial n}{\partial t'}\left(2 + \frac{t}{t'}\ln(\psi e)\right) - \frac{Tt}{t'^4}\psi^{t/t'}; \qquad (7)
\end{aligned}
$$

$n'(t')$ vanishes at the origin and the point at infinity, and it, as well as its first derivative, is continuous elsewhere. Therefore, the extremals are the positive, finite zeros of the derivative. The latter vanishes if, and only if, the logarithmic term does, indicating that, all else fixed, the dwell time during an individual interrogation should be so chosen as to yield a single glimpse probability of e^{-1} at the desired range, if the mean time between successive contacts is to be minimized. That the choice is the unique optimum in this sense follows immediately upon noting that the second derivative is negative definite when the first derivative vanishes.

Before turning briefly to the analysis of the quality of the output data as a function of the information rate provided by the sensor, it should be pointed out that other reasonable optimization criteria may be hypothesized. For example, instead of seeking to maximize the number of successful interrogations of the contact obtained over some time interval, as has been done above, the sampling rate may be so chosen as to maximize $\tilde{P}$, the probability that at least one successful interrogation results. That is, because of stringent bandwidth and storage restrictions, the data processing logic may be so arranged as to discard the trajectory if, on account of a continuous succession of fruitless interrogations, the prediction time, measured from the last contact, exceeds some predetermined figure.

It is apparent that, subject to the same assumptions and notation used above,

$$\tilde{P} = 1 - (1 - \psi_R^{t/t'})^{T/t'}, \tag{8}$$

partial differentiation of which with respect to t' shows that the extremals are the zeros of

$$y = (1 - \psi_R^{t/t'}) \ln (1 - \psi_R^{t/t'}) - \psi_R^{t/t'} \ln \psi_R^{t/t'}. \tag{9}$$

From inspection, they are determined by allowing the resultant single glimpse probability to assume the values 0, $\frac{1}{2}$, and 1. The first and last are physically meaningless, since the indicated sampling intervals are, respectively, infinitesimal and infinite. Indeed, consideration of the limiting behavior of (8) shows that they are minima so that, by virtue of the continuity of $\tilde{P}$, it must follow that system performance is uniquely optimized in this sense by choosing the signal integration times in such a manner that, all else fixed, it is equiprobable that an individual interrogation succeed or fail at the desired relative range.

The conflict among the optima is apparent since the ratio of the maximum information rate sampling interval to that derived immediately above is ln 2 for both passive and active search. Further, if P_0, t_0 and $\tilde{P}$, $\tilde{t}$ denote the cumulative detection probabilities and sampling intervals associated respectively with the former and the latter choices of optimization criteria, (6) yields

$$P_0 = 1 - \exp\left[-\frac{R}{Vt_0}\cdot N(1)\right],$$

$$\tilde{P} = 1 - \exp\left[-\frac{R}{V\tilde{t}} N(\ln^{1/\nu} 2)\right], \tag{10}$$

from which, eliminating R/V,

$$P_0 = 1 - (1 - \tilde{P})^{(1/\ln 2)N(1)/N(\ln^{1/\nu} 2)}. \tag{11}$$

Numerical analysis of the function $N(x)$ reveals that the exponent $N(1)/N(\ln^{1/\nu} 2) \ln 2$ is 0.67 or 0.83, according to whether the search conducted is active or passive. However, in both instances, it then follows that $\tilde{P}$ always exceeds P_0.

The specific nature and quality of the data to be derived by the sensor-computer may vary considerably from estimation of the bearing angle alone to comparatively sophisticated analyses of the implied trajectory of the contact. If the errors in the determination of any appropriate, related quantity are randomly distributed in each observation and a best estimate is to be formed upon the basis of some sufficiently lengthy sequence of interrogations, a reasonable figure of merit for the appraisal of system performance is the influence upon the variance of the failure of the sensor or the data processing subsystem to obtain or achieve the correlation of the necessary observations. Alternately stated, as the number of available observations that relate to a given contact decline, the variance of the resultant best estimate of the desired quantity must increase.

The further statistical study of the choice of the rate at which the potential contact space is to be interrogated requires a sampling theorem [3] which states that if the variance and the probability of obtaining each of a series of n observations is fixed, which is in accord with the assumption that the observer-contact relative geometry is essentially invariant during the sampling interval, the ratio ρ of σ_p^2, the anticipated variance of the best estimate based upon a sequence of trials whose length is statistical, to σ^2, the idealized variance based upon estimates in which all interrogations were successful is, for n large, inversely proportional to the probability p of obtaining an individual observation. If the data processing subsystem is assumed not to degrade the sensor-provided information, p is precisely the single glimpse probability of detection ψ. In a sense, the preceding states that, as the idealized number of samples increases, the expected variance of the resultant best estimate is inversely proportional to the expected number of samples available for analysis. Demonstration is required despite the obvious appeal to instinct, since it is only infrequently that the expected value of a function of a statistically distributed variable is equal to the function of the expected value of the variable.

In this instance the function is $1/x$, where the argument assumes positive integral values, λ, the probability of λ being

$$\psi^\lambda (1 - \psi)^{n-\lambda} \binom{n}{\lambda},$$

since its distribution is Bernoullian.

Writing σ^2 in the form k/n, where k is some unspecified function of the particle and the sensor-computer system, and forming the weighted mean of expressions of the form k/λ, $1 \leq \lambda \leq n$,

$$\rho = \frac{\sigma_p^2}{\sigma^2} = \frac{1}{1 - (1 - \psi)^n} \cdot \sum_{\lambda=1}^{n} \frac{k}{\lambda} \binom{n}{\lambda} \psi^\lambda (1 - \psi)^{n-\lambda} \bigg/ \left(\frac{k}{n}\right). \tag{12}$$

Since ψ must be bounded away from zero if the problem is to be physically meaningful, the cumulative probability of obtaining at least one observation, appearing in the denominator of the right side of (12), approaches unity in the limit. Replacing n/λ by the exponential integral appearing in the summation below, it suffices to consider

$$\rho \simeq \sum_{\lambda=1}^{n} \binom{n}{\lambda} \psi^\lambda (1 - \psi)^{n-\lambda} \int_0^\infty e^{-t\lambda/n} dt. \tag{13}$$

Upon inversion of the order of summation, (13) assumes the form

$$\rho \simeq \int_0^\infty \left\{ \sum_{\lambda=1}^{n} (\psi e^{-t/n})^\lambda (1 - \psi)^{n-\lambda} \binom{n}{\lambda} \right\} dt$$

$$= \int_0^\infty \{ [1 - (1 - e^{-t/n})\psi]^n - [1 - \psi]^n \} dt. \tag{14}$$

Neglecting for the moment the issue of the admissability of the inversion of the order of integration and the limiting process, since $[1-\psi]^n$ vanishes in the limit, only the behavior of

$$\phi(n) = [1 - (1 - e^{-t/n})\psi]^n \tag{15}$$

for n large is of interest. Taking the logarithm of both sides of (14), application of l'Hospital's rule yields

$$\ln \phi = \frac{\ln [1 - (1 - e^{-t/n})\psi]}{1/n}$$

$$\simeq \frac{-n^2\psi\left(\dfrac{t}{n^2} e^{-t/n}\right)}{1 - (1 - e^{-t/n})\psi} \simeq -\psi t. \tag{16}$$

Accordingly, the integrand goes to $e^{-\psi t}$ whence, by inference, $\rho \simeq 1/\psi$, which was to be shown. However, for all n the integrand is continuous and approaches its limit uniformly over any finite subinterval of the region of integration. Further, for all α, $0<\alpha<\psi$, $e^{-\alpha t}$ is integrable and dominates $e^{-\psi t}$ for positive t and, in turn, the integrand. These conditions are sufficient for the inversion of the limit to be admissible, thereby establishing the result.

In an idealized system, the signal-to-noise voltage ratio and, in turn, the standard deviation of the individual estimate of a directly observed quantity, such as the bearing angle of the contact, may be taken as inversely proportional to the square root of the integration time. On the other hand, the standard deviation of the best estimate varies inversely as the square root of the number of observations, where the latter is directly proportional to the sampling rate if, as has been hypothesized, the time interval over which the sequence of interrogations must be made is specified. It follows, then, that the variance of the best estimate obtainable, if all the interrogations are successful, is independent of the sampling rate. Accordingly, the statistical theorem derived above states that the dependence of the anticipated variance upon the sampling rate is determined only by the functional dependence of the single glimpse probability upon that latter quantity. In particular, the variance of the best estimate increases with the sampling rate. By way of an example, the variance in a maximum information rate system will be greater by a factor of $e/2$ than that in which the probability of at least one observation during the stipulated time interval is optimized.

It is apparent from the preceding discussion that the hypervelocity closure rates and short reaction time requirements, which necessitate high sampling rates, substantially influence detection system performance beyond the more obvious purely geometric degradation that will be investigated next. Certainly the choice of an appropriate sampling rate is seen not to be an elementary consideration in this instance and, from the preceding, it should be as small as is consistent with the over-all response times of the detection system and the kinematic behavior of the astronautical vehicle.

III. Some Implications of the Preceding

A. *The Dependence of Detection Performance Upon the Closure Rate*

The influence of the unfavorable operational environment defined by hypervelocities and low signal amplitudes may be displayed in several ways. Qualitative physical reasoning as well as the preceding quantitative analysis indicate that the mean acquisition range $\overline{R}$ will decline as the situation is further degraded. Utilizing the continuous representation of the detection process developed above, the probability density of acquisitions is the two-branch function $-(dP/dR)/P(0)$ for $R \geq 0$ and the null function for R negative. $\overline{R}$ then assumes the form

$$\overline{R} = -\frac{1}{P(0)} \int_0^\infty \left(R \frac{dP}{dR}\right) dR$$

$$= \frac{1}{P(0)} \left\{ \int_0^\infty P(R) dR - \lim_{R\to\infty} RP(R) \right\}, \tag{17}$$

the right-hand side of which results from integration by parts. $P(R)$ is a bounded function so that $RP(R)$ vanishes at the lower limit. Further, $P(R)$ goes to zero for R large and the logarithmic function in the integrand in $P(R)$ may be replaced by its exponential part. L'Hospital's theorem may then be applied to

$$\lim_{R\to\infty} \left\{1 - \exp\left[\frac{1}{Vt}\int_R^\infty \ln (1 - e^{-\alpha\rho^\nu}) d\rho\right]\right\} \bigg/ \frac{1}{R}$$

$$\approx \lim_{R\to\infty} \left\{1 - \exp\left[-\frac{1}{Vt}\int_R^\infty e^{-\alpha\rho^\nu} d\rho\right]\right\} \bigg/ \frac{1}{R} \cdot \tag{18}$$

The differentiation process yields $R^2 e^{-\alpha R^\nu}/Vt$, which goes to zero so that the weighted mean detection range is merely the ratio of the integral of the cumulative probability function over the entire positive half axis and its value at the origin.

Let $\overline{R}(v)$ and $\overline{R}(V)$ represent mean ranges derived under conditions of closure rates v and V, respectively. If the ratio of the velocities v/V assumes some constant value k, but each becomes indefinitely large, the nature of the dependence of $\overline{R}$ upon the relative velocity may be investigated by examining the behavior in the limit of the ratio,

$$\frac{R(v)}{\overline{R}(V)} = \left\{\frac{1 - e^{(1/Vt)F(0)}}{1 - e^{(1/kVt)F(0)}}\right\}$$

$$\cdot \left\{ \frac{\displaystyle\int_0^\infty [1 - e^{(1/kVt)F(R)}] dR}{\displaystyle\int_0^\infty [1 - e^{(1/Vt)F(R)}] dR} \right\}, \tag{19}$$

where $F(R)$ denotes the logarithmic integral which appears in $P(R)$.

As V becomes sufficiently large, the exponentials in (19) may be replaced by the first two terms of their Maclaurin developments, from which the product of the bracketed expressions is seen to be unity. Accordingly, the sensitivity of the weighted mean range to moderate changes in closure rate, such as would be introduced by variation of the bearing angles under consideration, declines at hypervelocities.

In general, sophistication of the analysis of detection system performance is readily shown to be of declining utility with small signal amplitudes in that the weighted mean range ceases to be a complex function of the relative motion, and increasingly conforms to the elementary range equations. That is, considering $\overline{R}$ as a function of the signal power $\overline{S}$, a change to $k\overline{S}$ alters the initial mean acquisition range by a factor of $k^{1/\nu}$. This follows immediately from an argument similar to that used above. Writing

$$\frac{\overline{R}(k\overline{S})}{\overline{R}(\overline{S})} = \left\{\frac{1-\exp\left[\dfrac{1}{Vt}\displaystyle\int_0^\infty \ln\left(1-e^{-a\rho^\nu/\overline{S}}\right)d\rho\right]}{1-\exp\left[\dfrac{1}{Vt}\displaystyle\int^\infty \ln\left(1-e^{-a\rho^\nu/k\overline{S}}\right)d\rho\right]}\right\}$$

$$\cdot\left\{\frac{\displaystyle\int_0^\infty\left[1-\exp\left[-\left(\frac{R}{Vt}N(Ra^{1/\nu}/(k\overline{S})^{1/\nu})\right)\right]dR\right.}{\displaystyle\int_0^\infty\left[1-\exp\left[-\left(\frac{R}{Vt}N(Ra^{1/\nu}/\overline{S}^{1/\nu})\right)\right]dR\right.}\right\}, \quad (20)$$

which, following a change of variable of the form $R/c=\phi$ in the above integrals, may be written

$$\frac{\overline{R}(k\overline{S})}{\overline{R}(\overline{S})} = k^{1/\nu}\left\{\frac{1-\exp\left[\dfrac{\overline{S}^{1/\nu}}{Vt}\displaystyle\int_0^\infty \ln\left(1-e^{-a\phi^\nu}\right)d\phi\right]}{1-\exp\left[\dfrac{(k\overline{S})^{1/\nu}}{Vt}\displaystyle\int_0^\infty \ln\left(1-e^{-a\phi^\nu}\right)d\phi\right]}\right\}\cdot\left\{\frac{\displaystyle\int_0^\infty\left[1-\exp\frac{(k\overline{S})^{1/\nu}}{Vt}\int_\phi^\infty \ln\left(1-e^{-at^\nu}\right)dt\right]d\phi}{\displaystyle\int_0^\infty\left[1-\exp\frac{\overline{S}^{1/\nu}}{Vt}\int_\phi^\infty \ln\left(1-e^{-at^\nu}\right)dt\right]d\phi}\right\}. \quad (21)$$

As $\overline{S}$ becomes sufficiently small, the exponentials in (21) may be replaced by the first two terms of their Maclaurin development, leading directly to the required result. It should be noted that the conclusion is not contingent upon the assumption of a Rayleigh model, since the reasoning would proceed in an identical manner for all $\psi(\overline{S}/r^\nu)$, where r is the instantaneous relative range.

Unfortunately, while the preceding observations on the behavior of the weighted mean range present an interesting aspect of the detection process, it is very limited in scope. A more meaningful measure of system performance is the influence of the environment upon the cumulative probability, since survival is dependent upon detection outside some range barrier that is largely dictated by response delays introduced by the decision-making apparatus. Before introducing this latter consideration, some review of fundamental system behavior with respect to $P(V)$ is advantageous.

Fixing the range for the moment and examining the limiting behavior of $P(v)/P(V)$, as had been done above in the case of the weighted mean acquisition range, from (4),

$$\frac{P(v)}{P(V)} = \left\{1-e^{-(R/kVt)N(R\alpha^{1/\nu})}\right\}/\left\{1-e^{-(R/VE)N(R\alpha^{1/\nu})}\right\}, \quad (22)$$

which, for V large, is asymptotic to k^{-1}. Accordingly, at hypervelocities, the cumulative detection probability displays an approximate inverse dependence upon the closure rate. This is in marked conflict with the likelihood of potential collision contacts, which is proportional to the relative velocity. The preceding observation obtains whether the system performance degradation is caused by extreme closure rates or reduced signal amplitudes. This is readily established by recalling that α varies inversely as the mean signal power density, and by noting that $N(x)$ vanishes in the limit for x large. The result then follows by application of l'Hospital's theorem or by considering the magnitude of the terms in the Maclaurin development of the exponentials in (22) in powers of their exponents.

In actuality, of course, the degradation caused by even moderate increases in relative velocity is more substantial than has been indicated above, since, as has been mentioned earlier, at a given bearing the required detection range should be very nearly proportional to the corresponding closure rate. It is readily shown that the velocity dependence is then of a much higher order than that displayed above by again investigating the limiting behavior of $P(v)/P(V)$. In this instance,

$$\frac{P(v)}{P(V)} = \frac{1-\exp\left[\dfrac{1}{kVt}\displaystyle\int_{kV\mathfrak{J}}^\infty \ln\left(1-e^{-\alpha\rho^\nu}\right)d\rho\right]}{1-\exp\left[\dfrac{1}{Vt}\displaystyle\int_{V\mathfrak{J}}^\infty \ln\left(1-e^{-\alpha\rho^\nu}\right)d\rho\right]}$$

$$\sim\frac{1}{k}\,\frac{\displaystyle\int_{kV\mathfrak{J}}^\infty \ln\left(1-e^{-\alpha\rho^\nu}\right)d\rho\,,}{\displaystyle\int_{V\mathfrak{J}}^\infty \ln\left(1-e^{-\alpha\rho^\nu}\right)d\rho}, \quad (23)$$

where $\mathfrak{J}$ is the over-all time constant of system response to the warning, and the indicated asymptotic behavior follows immediately from the observation that the exponents that appear are very rapidly decreasing functions of V. Differentiation of numerator and denominator and replacement of the resultant logarithmic expressions by the first term of their Maclaurin development leads to

$$\frac{P(v)}{P(V)} \sim {}^{\alpha(V\mathfrak{J})^{\nu}(1-k^{\nu})}. \qquad (24)$$

Unlike the earlier fixed range example, the above approaches a limit for large V if, and only if, k is greater than unity. Physically, this suggests that even modest increases in closure rate will produce a very marked decay in the system performance, as is evidenced by the now exponential dependence upon that variable.

It is of interest to obtain a somewhat more quantitative insight into the behavior of $P(V\mathfrak{J})$. Assuming the preceding to be known, one might then inquire as to the cumulative detection probability p corresponding to some new closure rate v. From (6),

$$\psi_R = \exp\left\{-\left[N^{-1}\left(\frac{t}{\mathfrak{J}}\ln(1-P)^{-1}\right)\right]^{\nu}\right\}. \qquad (25)$$

But the single glimpse detection probability at the new required detection range is $\psi_R{}^{(v/V)}$ from which, by (6),

$$p = 1-\exp\left\{-\frac{\mathfrak{J}}{t}\,N\left[\frac{v}{V}\,N^{-1}\left(\frac{t}{\mathfrak{J}}\ln(1-P)^{-1}\right)\right]\right\}, \qquad (26)$$

where $N^{-1}(x)$ denotes the inverse function.

The numeric solution to the problem at hand is, in effect, set forth in Fig. 1. Calculating the ordinate, the inverse, which is the corresponding single glimpse probability, is then found from the appropriate contour raised to the v/V power, and the new ordinate found. The remaining calculations are trivial.

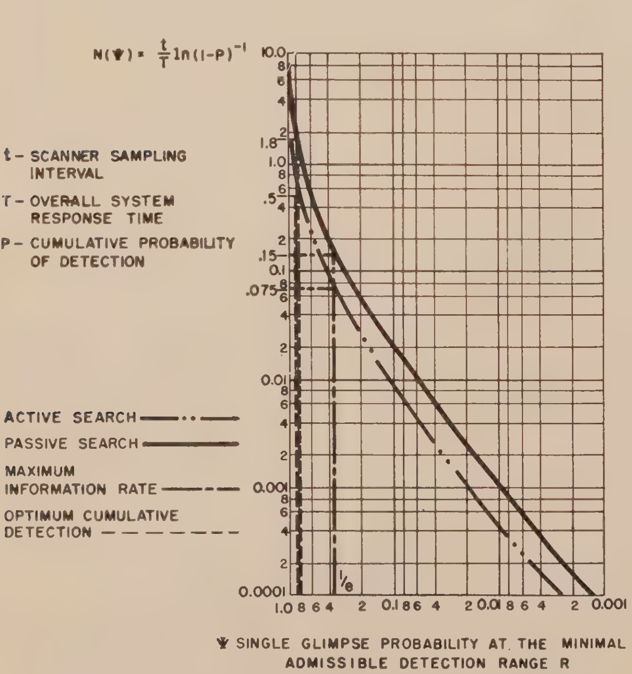

Fig. 1.

A representative numeric example will be illustrative of the manner of application and the pronounced dependence of the system upon V. To demonstrate the effect of a nominal increase in V of 0.1, assume $P=0.9$ for an active system characterized by a time constant to frame time ratio of 5. The inverse of $N(x)=\frac{1}{5}\ln(1-P)^{-1}$ is 0.71. Correcting for the velocity increase, the required single glimpse probability is 0.69^{-}, the reduction being caused by the fact that the desired detection range must increase with the closure rate. The corresponding value of N is 0.32 from which $p=1-\exp[-5(0.31)]=0.80$, which is a reasonably substantial degradation in view of the very moderate increase in relative velocity. A corresponding calculation for $P=0.5$ yields $p=0.3$, an even larger percentile decline in performance, whereas no change in the required cumulative detection probability is discernible if its initial value is 0.95. The preceding displays an important consideration in warning system design. In effect, detection performance must be good everywhere, or it is good nowhere, if the possible contact space is uniformly covered.

B. The Cumulative Influence of the Closure Rate

The conflict between the performance at various bearing angles and the requirements introduced by the bearing dependent frequency of potential collision contacts has been noted above. A useful measure of system effectiveness can be obtained by cascading the two phenomena.

In the analysis that follows, $\bar{P}$ denotes the likelihood of such a contact during some differential time interval ϵ, and P denotes the probability of discerning the contact by the minimal range and responding by some appropriate action. Then, the likelihood of surviving beyond that interval is $P\,\bar{P}+(1-\bar{P})$. Noting that $\bar{P}$ is of the form $\rho\epsilon V/T$, where ρ is a constant that reflects the particle density and T is the time duration of the flight, S, the likelihood of survival during some differential time interval with no collisions from some given bearing sector characterized by closure rates V, is given by

$$S = \lim_{\epsilon\to 0}\left[1-(1-P)\rho V\epsilon/T\right]^{T/\epsilon} = e^{-CV(1-P)}, \qquad (27)$$

where C is a parameter that reflects environmental and system characteristics.

Plainly, S decays with increasing V since both factors of $V(1-P)$ are monotone increasing functions of V. It is reasonable to require equivalent performance in all feasible contact sectors, thereby leading to the idealized functional form $P=1-K^2/V$, if the exponential in (27) is to be constant. This is in obvious conflict with the functional behavior of what has been studied thus far and, indeed, is impossible for V sufficiently small, since P would then assume negative values. This latter contingency would not appear to be of concern in the case of astronautical vehicles in view of the anticipated particle velocities. In general, the factor $1-P$ is a far greater contributor to the variation with velocity of (27) than is the linear function V. Accordingly, the detection process will later be suboptimized by attempting to maintain $P(\beta)$ constant through variation of the search system dwell.

It will be well to accomplish some numerical analysis of the over-all degradation in terms of (27) before departing from this point. To demonstrate the consequences of a uniform rate of interrogation of the space volume, the earlier calculations will be extended. Let S denote the likelihood of adequate coverage over some sector characterized by collision closure rate V, subject to which the detection system yielded a cumulative probability of P. Then at another bearing angle whose corresponding parameters are v, p, the survival probability s is, from the above,

$$s = S^{v(1-p)/V(1-P)} = S^{v/V(1-p)V/v-1}.$$

It is apparent from the form of (28) that, as before, the degradations caused by an increased V are magnified as the initial likelihood of survival declines. On the other hand, the sensitivity to a modest increase in the ratio v/V declines with P, though it may be expected that S and P will simultaneously be high.

IV. Suboptimization in the Case of Randomly Moving Particles

As indicated above, the distribution of dwell time will now be specified subject to the constraints that $P(V\mathfrak{J})$ is to be maintained constant while the sweep time or search interval t is fixed. It is, of course, possible to investigate this problem without the latter constraint. However, sensor performance, computer bandwidth limitations in the data processing and decision-making apparatus would appear to establish the maximum rate at which information can be accepted for processing.

The desired result can be established without reference to the specific exponential form of the Rayleigh target. Since the signal integration time is inversely proportional to ω, the rate at which the angular sector is swept, the single glimpse probability will be assumed to be of the form $\psi(\rho\omega^{1/\nu})$ where ν has the same significance as before. One must then have

$$P = 1 - \exp\left[\frac{1}{V(\beta)/}\int_{V(\beta)\mathfrak{J}}^{\infty} \ln\left\{1 - \psi\left[\rho\omega^{1/\nu}(\beta)\right]\right\} d\rho\right] \quad (29)$$

which, following the substitution $\rho\omega^{1/\nu}(\beta) = \phi$, may be written

$$P=1-\exp\left\{-\frac{\mathfrak{J}}{t}\left[\frac{1}{\mathfrak{J}V\omega^{1/\nu}}\int_{\mathfrak{J}V\omega^{1/\nu}}^{\infty} \ln\left[1-\psi(\phi)\right]d\phi\right]\right\}. \quad (30)$$

It is apparent from the above that if $V\omega^{1/\nu}$ is maintained constant, P will be invariant with respect to the bearing angle. Alternately stated, the search dwell times should be so chosen that the integrated signal is proportional to the probability density of potential collision contacts raised to the $\nu/2$ power.

It is instructive to complete the analysis for the important case in which the search is conducted over the plane of motion of the observer. The vector diagram for collision immediately yields

$$0 = V^2 - 2vV\cos\beta - (v_p^2 - v^2), \quad (31)$$

where v, v_p denote, respectively, the absolute values of the velocity vectors of the observer and particle, and V denotes the relative velocity of approach. The preceding quadratic equation then yields

$$\begin{aligned} V &= v\cos\beta \pm \sqrt{(v_p^2 - v^2\sin^2\beta)} \\ &= v\cos\beta \pm \sqrt{\left[\left(v_p^2 - \frac{v^2}{2}\right) + \frac{v^2}{2}\cos 2\beta\right]}, \end{aligned} \quad (32)$$

which displays the well-known properties that for $v > v_p$ there are two solutions over the regions $0 \leq \beta < \sin^{-1} v_p/v$, one at the upper boundary and none beyond. From the condition that the frame time t is specified and the preceding analysis which states that one must select $\omega^{-1} = K^{-1}V^{\nu}$, for $v \leq v_p$, the case of greatest interest,

$$\begin{aligned} t &= \int_{-\pi}^{\pi} \frac{d\beta}{\omega} = \frac{2}{K}\int_0^{\pi} V^{\nu}(\beta)d\beta \\ &= \frac{2}{K}\int_0^{\pi} (v_p^2 + v^2\cos 2\beta)d\beta \\ &\quad \pm \frac{4v}{K}\int_0^{\pi} \cos\beta\sqrt{\left[\left(v_p^2 - \frac{v^2}{2}\right) + \frac{v^2}{2}\cos 2\beta\right]}d\beta \end{aligned} \quad (33)$$

for passive systems, and, for active search,

$$\begin{aligned} t &= \frac{2}{K}\int_0^{\pi} (v^4\cos 4\beta + 2v^2v_p^2\cos 2\beta + v_p^4)d\beta \\ &\quad \pm \frac{8v}{K}\int_0^{\pi} \cos\beta\{v^2\cos 2\beta + v_p^2\} \\ &\qquad \cdot\sqrt{\left[\left(v_p^2 - \frac{v^2}{2}\right) + \frac{v^2}{2}\cos 2\beta\right]}d\beta. \end{aligned} \quad (34)$$

Consideration of the symmetry and sense of the trigonometric functions show that integrals of $\cos\beta f(\cos 2\beta)$ over $0 \leq \beta \leq \pi$ are null. Accordingly, K is $2\pi v_p^{\nu}/t$ and, writing $r = v/v_p$,

$$\omega = \frac{2\pi}{t}\left(\frac{v_p}{V}\right)^{\nu} = \frac{2\pi}{t}\left[r\cos\beta + \sqrt{(1 - r^2\sin^2\beta)}\right]^{-\nu}, \quad (35)$$

where, as before, ν is 2 or 4 according to whether the search involves passive or active equipment. From (35) it is apparent that ω is a stronger function of β in the latter case. However, in both instances the functional dependence of the optimum scan rate upon the bearing angle declines with r, which is in accord with physical reasoning. The analysis in 3 dimensions proceeds in an identical manner, K being altered.

The above discussion established the required program for the distribution of the search effort subject to some specified sampling interval. To complete the analysis, it is necessary to develop a rational basis for the choice of the frequency with which the potential contact space is to be interrogated. It will now be shown that if, as has been done, only signal integration time is considered, a sampling interval exists which is optimum in the sense that it maximizes the cumulative probability of detection at some stipulated desired range. Since, as has been noted, the latter is dependent only upon the anticipated closure rate and the system reaction time, and since, all else fixed, the signal level $S(t)$ is a monotone increasing function of the integration time, the cumulative probability of detection assumes the form

$$P(t) = 1 - \exp\left[\frac{1}{Vt}\int_{V\mathfrak{J}}^{\infty} \ln\left(1 - \phi(t)e^{-a\rho^{\nu}/S}\right)d\rho\right]$$
$$= 1 - \exp\left[\frac{1}{V}\,\frac{F(t)}{t}\right]. \tag{36}$$

$\phi(t)$ is a generalized degradation factor that reflects the efficiency of the data handling subsystem. Explicitly, it measures the probability that cognizance is taken of the individual sensor outputs and is therefore a positive function, bounded above by unity.

Only the behavior of $F(t)/t$ need be investigated. The latter ratio may be exhibited in the form,

$$\frac{F(t)}{t} = -\frac{1}{t}\int_{V\mathfrak{J}}^{\infty}\left\{\sum_{\lambda=1}^{\infty}\frac{\phi^{\lambda}(t)}{\lambda}\,e^{-\lambda a\rho^{\nu}/S(t)}\right\}d\rho$$
$$= -\frac{1}{t}\sum_{\lambda=1}^{\infty}\frac{\phi^{\lambda}}{\lambda}\int_{V\mathfrak{J}}^{\infty}e^{-\lambda a\rho^{\nu}/S}d\rho$$
$$= -\frac{1}{\nu a^{1/\nu}}\sum_{\lambda=1}^{\infty}\frac{1}{\lambda^{1+1/\nu}}$$
$$\cdot\left\{\phi^{\lambda}\,\frac{S^{1/\nu}}{t}\int_{\lambda a\ S(V\mathfrak{J})^{\nu}}^{\infty}e^{-x}x^{1/\nu-1}dx\right\}. \tag{37}$$

For t sufficiently small, the bracketed factor $g(t)$ in the generating term of the above infinite series obeys the train of inequalities,

$$0 \leq g(t) \leq \frac{S}{t}\left[\lambda a(V\mathfrak{J})^{\nu}\right]^{1/\nu-1}\int_{\lambda a/S(V\mathfrak{J})^{\nu}}^{\infty}e^{-x}dx$$
$$= \frac{S}{t}\left[\lambda a(V\mathfrak{J})^{\nu}\right]^{1/\nu-1}e^{-(\lambda a/S)(V\mathfrak{J})^{\nu}}. \tag{38}$$

Ideally, the mean signal to root-mean-square noise voltage ratio is proportional to $\sqrt{t}$, in which case $S(t)$ may be taken as proportional to t. The upper bound then vanishes with t because of the behavior of the exponential factor. Indeed, there appears to be no physically meaningful sensor and signal integration process that may be characterized by an $S(t)$ that has a zero at the origin of sufficiently low order to yield other than a zero limit for $F(t)/t$ and, in turn, $P(t)$, which displays the same asymptotic behavior for t small.

$$\left|\frac{F(t)}{t}\right| = \frac{1}{t\nu a^{1/\nu}}\sum_{\lambda=1}^{\infty}\frac{\phi^{\lambda}S^{1/\nu}}{\lambda^{1+1/\nu}}\left(\int_{0}^{\infty} - \int_{0}^{\lambda a/S(V\mathfrak{J})^{\nu}}\right)e^{-x}x^{1/\nu-1}dx$$
$$= \frac{1}{t\nu a^{1/\nu}}\sum_{\lambda=1}^{\infty}\frac{\phi^{\lambda}}{\lambda^{1+1/\nu}}\left\{\Gamma\left(\frac{1}{\nu}\right) - \gamma\left(\frac{1}{\nu},\,\frac{\lambda a}{S}(V\mathfrak{J})^{\nu}\right)\right\}$$
$$< \frac{\Gamma\left(\dfrac{1}{\nu}\right)S^{1/\nu}}{t\nu a^{1/\nu}}\,\zeta\left(1 + \frac{1}{\nu}\right), \tag{39}$$

where $\Gamma(n)$ and $\gamma(n, x)$ represent the complete and incomplete gamma functions, respectively, in the notation of Legendre, and $\zeta(x)$ is the Riemann zeta function. In general, t is far more rapidly increasing than is $S^{1/\nu}(t)$ which, for many classes of integrators, is bounded above. Accordingly, $S^{1/\nu}(t)/t$ vanishes in the limit as the sampling interval becomes indefinitely large, as in the case of the idealized integrator previously cited. In that instance the result follows immediately since the variable appears only in the denominator which contains the factor $t^{1-1/\nu}$, the exponent being positive. Since $P(t)$ is positive, nonconstant, and vanishes in the limit at both the origin and the point at infinity, it must have at least one maximum, which was to be shown.

The uniqueness of the optimum scan interval could not be established with the highly generalized detection processes considered above. However, if an idealized signal integration process and an essentially unsaturated data handling subsystem are assumed, in this, the most important case, the uniqueness can be readily established. Differentiation of $F(t)/t$ with respect to the sampling interval yields

$$\frac{\partial}{\partial t}\left(\frac{F(t)}{t}\right)$$
$$= -\frac{F(t)}{t^{2}} + \frac{1}{t}\int_{V\mathfrak{J}}^{\infty}\frac{\partial}{\partial t}\ln\left(1 - e^{-a\rho^{\nu}/t}\right)d\rho. \tag{40}$$

The partial derivative of the integrand is

$$-\frac{a}{t^{2}}\,\rho^{\nu}e^{-a\rho^{\nu}/t}/\left(1 - e^{-a\rho^{\nu}/t}\right)$$
$$= -\frac{\rho}{\nu t}\,\frac{\partial}{\partial\rho}\ln\left(1 - e^{-a\rho^{\nu}/t}\right), \tag{41}$$

from which integration by parts yields

$$\frac{\partial}{\partial t}\left(\frac{F(t)}{t}\right)$$
$$= -\frac{1}{\nu t^{2}}\left\{(\nu - 1)F(t) - V\mathfrak{J}\ln\left(1 - e^{-a(V\mathfrak{J})^{\nu}/t}\right)\right\}. \tag{42}$$

From the earlier discussion, the possible zeros at the origin and the point at infinity are not of interest, so that the desired extremals are the finite zeros of the numerator at other than the origin.

Accordingly,

$$\frac{F(t)}{Vt} = \frac{\mathfrak{J}}{(\nu - 1)t} \ln \left(1 - e^{-a(V\mathfrak{J})^{\nu}/t}\right) \tag{43}$$

and

$$P = 1 - \left(1 - e^{-a(V\mathfrak{J})^{\nu}/t}\right)^{\mathfrak{J}/(\nu-1)t} \tag{44}$$

in the vicinity of a maximum (or a minimum). Verbalized, if the scan rate of a detector has been properly chosen, the cumulative detection probability at the range at which performance is optimized is the same as if $1/(\nu-1)$ of the remaining possible scans were taken at the single-glimpse probability which obtains at the range in question. Writing (44) in the form,

$$\frac{t}{\mathfrak{J}} \ln (1 - P)^{-1} = \frac{1}{\nu - 1} \ln (1 - \psi)^{-1}, \tag{45}$$

the desired extremals may be readily found through graphic solution by constructing the right-hand function on Fig. 1. The resultant optima for both passive and active systems, which are very nearly identical, as well as the value of $N(\psi)$ for the maximum information rate choice of the sampling interval, are displayed.

Unless optimization in the above sense is being accomplished in the vicinity of reasonably high signal levels, the required signal integration may lead to unacceptably low information rates over the scanned space since the required single glimpse probabilities are of the order of 0.8. This is particularly true in the case of the low signal amplitude, hypervelocity closure rate environment under consideration, leading thereby to the conclusion that it may not be possible to so optimize astronautical vehicle search systems. However, the information content derived during an individual interrogation improves with increased dwell times, implying that the optimal search rates in this application are intermediate between the extremes dictated by tracking considerations and detection in the classical sense.

V. PARTICULARIZATION OF SEARCH DURING MOTION UNDER A CENTRAL FORCE FIELD

Let $\mathbf{P}$, $\mathbf{p}$ represent, respectively, the position vectors of the astronautical vehicle and another particle, both moving freely under the influence of a central force field, the source of which is located at the origin of vectors. It will be further assumed that M, the mass of the latter body, is extremely large with respect to that of either of the others and that there is no discernible gravitational interaction between the astronaut and the other particle. As is apparent, the preceding conditions characterize the environmental kinematics of space.

From the above constraints, by use of the dot superscript notation to indicate time derivatives, one may write for the pertinent differential equations of motion,

$$\ddot{\mathbf{P}} = \mathbf{P}f(|\mathbf{P}|), \qquad \ddot{\mathbf{p}} = \mathbf{p}f(|\mathbf{p}|), \tag{46}$$

where $f(|A|)$ may be any well-behaved function of the absolute value of the position vector. It may be readily shown that despite the admissible approximation of uniform rectilinear motion in the vicinity of contact a collision course, defined in the conventional manner in which the relative velocity vector is coincident with the relative positional vector, is impossible unless both objects are on the degenerate linear orbit containing the center of force. Vectorially, this corresponds to stating that their cross product must vanish, or

$$0 = (\dot{\mathbf{p}} - \dot{\mathbf{P}}) \times (\mathbf{p} - \mathbf{P}), \tag{47}$$

which may be rearranged in the form,

$$\dot{\mathbf{p}} \times \mathbf{P} + \dot{\mathbf{P}} \times \mathbf{p} = \dot{\mathbf{p}} \times \mathbf{p} + \dot{\mathbf{P}} \times \mathbf{P}. \tag{48}$$

However, the derivative of the right side of the above must vanish identically since, as is well known, the areas swept per unit period of time by the radii vectors are constant. Differentiation of the left side of (48) leads to

$$\{\ddot{\mathbf{p}} \times \mathbf{P} + \ddot{\mathbf{P}} \times \mathbf{p}\} + \{\dot{\mathbf{p}} \times \dot{\mathbf{P}} + \dot{\mathbf{P}} \times \dot{\mathbf{p}}\} = 0, \tag{49}$$

where, plainly, the second bracketed quantity vanishes. Applying (46) to the remaining quantity, one must have

$$[f(|\mathbf{p}|) - f(|\mathbf{P}|)]\mathbf{p} \times \mathbf{P} = 0. \tag{50}$$

The scalar factor has, at best, isolated zeros unless the orbits are identical and, if not circular, they must be concurrently swept. Accordingly, the vector product $\mathbf{p}\times\mathbf{P}$ must be null for a finite interval preceding the contact, or $\mathbf{p}=m\mathbf{P}$, where m is some scalar quantity. Replacement of $\mathbf{p}$ and $\dot{\mathbf{p}}$ in (47) by the appropriate relationships in $\mathbf{P}$ and $\dot{\mathbf{P}}$, or the reverse, leads to

$$\begin{aligned} 0 &= [(\dot{m}\mathbf{P} + m\dot{\mathbf{P}}) - \dot{\mathbf{P}}] \times [(m\mathbf{P}) - \mathbf{P}] \\ &= (m-1)^2 \dot{\mathbf{P}} \times \mathbf{P} \end{aligned}$$

and

$$\begin{aligned} 0 &= \left[\dot{\mathbf{p}} - \frac{1}{m}\left(\frac{\dot{m}}{m}\mathbf{p} - \dot{\mathbf{p}}\right)\right] \times \left[\mathbf{p} - \left(\frac{1}{m}\mathbf{p}\right)\right] \\ &= \left(1 - \frac{1}{m^2}\right)\dot{\mathbf{p}} \times \mathbf{p}. \end{aligned} \tag{51}$$

Exclusive of the trivial case in which m is unity and the vectors are identical, the velocity and position vectors of each particle must be parallel, which was to be shown. Certainly, such trajectories are improbable since fuel consumption considerations dictate minimal energy paths such as the Hohmann cotangential ellipses.

However, despite the fact that in a precise sense a collision course is impossible except in a trivial case, certain general conclusions may be drawn regarding a feasible contact zone. It will now be shown that particles approaching with an essentially invariant bearing angle β must have relative trajectories that lie on a surface that is characterized by reasonable navigational system inputs relating to the motion of the astronautical vehicle in the central force field. Further, the surface will be seen to be independent of the specific nature of the law governing the intensity of the force field, though this observation is largely of academic interest since the inverse square law appears to fail only over regions that are either too close or too distant to the center of force to be of consequence. What is important, however, is that, referencing the earlier theory, confinement of the search to this limited region rather than interrogating omnidirectionally makes major improvements in detector performance possible.

Recognizing the essentially rectilinear nature of the motions of the astronautical vehicle and the contact, the left side of

$$-\dot{\tilde{\beta}}\sin\tilde{\beta} = \frac{d}{dt}\left\{\frac{[(\dot{\boldsymbol{p}}-\dot{\boldsymbol{P}})\cdot\dot{\boldsymbol{P}}]}{|\dot{\boldsymbol{p}}-\dot{\boldsymbol{P}}|\,|\dot{\boldsymbol{P}}|}\right\} \tag{52}$$

must vanish as the condition of warning. From the definition of the scalar product, $\tilde{\beta}$ is the supplement of the bearing angle. Accomplishing the indicated differentiation, (52) becomes

$$\begin{aligned}-\dot{\tilde{\beta}}\sin\tilde{\beta} = {} & \frac{[(\ddot{\boldsymbol{p}}-\ddot{\boldsymbol{P}})\cdot\dot{\boldsymbol{P}}]+[(\dot{\boldsymbol{p}}-\dot{\boldsymbol{P}})\cdot\ddot{\boldsymbol{P}}]}{|\dot{\boldsymbol{p}}-\dot{\boldsymbol{P}}|\,|\dot{\boldsymbol{P}}|} \\ & - \frac{[(\dot{\boldsymbol{p}}-\dot{\boldsymbol{P}})\cdot\dot{\boldsymbol{P}}]}{|\dot{\boldsymbol{p}}-\dot{\boldsymbol{P}}|^2|\dot{\boldsymbol{P}}|^2} \\ & \cdot\left\{|\dot{\boldsymbol{p}}-\dot{\boldsymbol{P}}|\frac{d}{dt}|\dot{\boldsymbol{P}}| + |\dot{\boldsymbol{P}}|\frac{d}{dt}|\dot{\boldsymbol{p}}-\dot{\boldsymbol{P}}|\right\}.\end{aligned} \tag{53}$$

Utilizing the fact that the derivative of the absolute value of any non-null vector $\boldsymbol{A}$ is $(\dot{\boldsymbol{A}}\cdot\boldsymbol{A})/|\boldsymbol{A}|$, (53) may be replaced by

$$\begin{aligned}-\dot{\tilde{\beta}}\sin\tilde{\beta} = {} & \frac{[(\ddot{\boldsymbol{p}}-\ddot{\boldsymbol{P}})\cdot\dot{\boldsymbol{P}}]+[(\dot{\boldsymbol{p}}-\dot{\boldsymbol{P}})\cdot\ddot{\boldsymbol{P}}]}{|\dot{\boldsymbol{p}}-\dot{\boldsymbol{P}}|\,|\dot{\boldsymbol{P}}|} \\ & - \frac{[(\dot{\boldsymbol{p}}-\dot{\boldsymbol{P}})\cdot\dot{\boldsymbol{P}}]}{|\dot{\boldsymbol{p}}-\dot{\boldsymbol{P}}|^2|\dot{\boldsymbol{p}}|^2}\left\{\frac{|\dot{\boldsymbol{p}}-\dot{\boldsymbol{P}}|}{|\dot{\boldsymbol{P}}|}(\dot{\boldsymbol{P}}\cdot\ddot{\boldsymbol{P}})\right. \\ & \left. + \frac{|\dot{\boldsymbol{P}}|}{|\dot{\boldsymbol{p}}-\dot{\boldsymbol{P}}|}[(\dot{\boldsymbol{p}}-\dot{\boldsymbol{P}})\cdot(\ddot{\boldsymbol{p}}-\ddot{\boldsymbol{P}})]\right\}\end{aligned} \tag{54}$$

and, finally, from (46), for all objects moving independently in a communal central force field,

$$\begin{aligned}-\dot{\tilde{\beta}}\sin\tilde{\beta} = {} & \{[(f(|\boldsymbol{p}|)\boldsymbol{p}-f(|\boldsymbol{P}|)\boldsymbol{P})\cdot\dot{\boldsymbol{P}}] \\ & + f(|\boldsymbol{P}|)[(\dot{\boldsymbol{p}}-\dot{\boldsymbol{P}})\cdot\boldsymbol{P}]\}\,|\dot{\boldsymbol{p}}-\dot{\boldsymbol{P}}|^{-1}|\dot{\boldsymbol{P}}|^{-1} \\ & - \frac{[(\dot{\boldsymbol{p}}-\dot{\boldsymbol{P}})\cdot\dot{\boldsymbol{P}}]}{|\dot{\boldsymbol{p}}-\dot{\boldsymbol{P}}|^2|\dot{\boldsymbol{P}}|^2}\left\{\frac{f(|\boldsymbol{P}|)\,|\dot{\boldsymbol{p}}-\dot{\boldsymbol{P}}|}{|\dot{\boldsymbol{P}}|}(\dot{\boldsymbol{P}}\cdot\boldsymbol{P})\right. \\ & + \frac{|\dot{\boldsymbol{P}}|}{|\dot{\boldsymbol{p}}-\dot{\boldsymbol{P}}|}[(\dot{\boldsymbol{p}}-\dot{\boldsymbol{P}})\cdot(f|\boldsymbol{p}|)\boldsymbol{p} \\ & \left. - f(|\boldsymbol{P}|)\boldsymbol{P}]\right\}.\end{aligned} \tag{55}$$

In the vicinity of impact, $\dot{\tilde{\beta}}\to 0$ and $\boldsymbol{p}\to\boldsymbol{P}$, so that

$$\begin{aligned}0 = {} & \frac{f(|\boldsymbol{P}|)}{|\dot{\boldsymbol{p}}-\dot{\boldsymbol{P}}|\,|\dot{\boldsymbol{P}}|}\left\{[(\dot{\boldsymbol{p}}-\dot{\boldsymbol{P}})\cdot\boldsymbol{P}]\right. \\ & \left. - \frac{[(\dot{\boldsymbol{p}}-\dot{\boldsymbol{P}})\cdot\dot{\boldsymbol{P}}](\dot{\boldsymbol{P}}\cdot\boldsymbol{P})}{|\dot{\boldsymbol{P}}|^2}\right\}.\end{aligned} \tag{56}$$

However, this is only possible if the bracketed expression vanishes. The latter condition may be exhibited in the form,

$$\frac{[(\dot{\boldsymbol{p}}-\dot{\boldsymbol{P}})\cdot\boldsymbol{P}]}{|\dot{\boldsymbol{p}}-\dot{\boldsymbol{P}}|\,|\boldsymbol{P}|} = \frac{[(\dot{\boldsymbol{p}}-\dot{\boldsymbol{P}})\cdot\dot{\boldsymbol{P}}]}{|\dot{\boldsymbol{p}}-\dot{\boldsymbol{P}}|\,|\dot{\boldsymbol{P}}|}\,\frac{(\dot{\boldsymbol{P}}\cdot\boldsymbol{P})}{|\dot{\boldsymbol{P}}|\,|\boldsymbol{P}|}$$

or

$$\cos\mu = \cos\tilde{\beta}\cos\gamma, \tag{57}$$

where μ is the angle between the relative velocity and astronaut positional vectors. γ, the angle between the velocity and positional vectors of the astronaut, may be presumed known. The relationship (57) defines a surface over which, viewed by the astronaut, the potential collision contact must make its relative terminal approach.

VI. CONCLUSIONS

1) Programmed space distribution of system search effort as a function of the geometry of the distribution of potential contacts and the anticipated relative closure rate is mandatory.

2) The probability of warning by some specified range of an impending collision markedly declines with increasing closure rates while, fixing over-all system response time, detection range requirements increase. Further, random particle distributions bias the frequency of potential collision contacts in the direction of the higher closure rates so that survival probability is seriously degraded if the observer space is omnidirectionally and uniformly interrogated by the search system.

3) All else equal, the number of successful interrogations per unit time interval of a Rayleigh contact by a continuously scanning system is maximized by choosing signal integration times that yield a single glimpse probability of $1/e$. The probability of receiving at least one

return in a given time interval is maximized by choosing integration times that yield a single glimpse probability of 1/2. Scan rates are thereby implied by automatic data handling needs that are substantially higher than those dictated by conventional criteria of optimal detection performance which conflict with the short system reaction time requirements.

4) If the rate at which observer space is interrogated has been chosen so as to yield the greatest attainable cumulative probability of detection at some specified range, the latter probability is that which would result if $1/(\nu-1)$ of the remaining scans preceding collision were made at the single glimpse probability which obtains at the range in question, ν being 4 or 2 according to whether the search system is active or passive.

5) If detection performance requirements are defined by over-all system response time so that the minimal admissible warning range is the product of the latter and the anticipated closure rate, and the closure rate is definable over the observer space, the probability of acquiring the contact by that critical range may be maintained constant over the potential contact space by choosing search system dwell times over each sector that are proportional to the $1/\nu$th power of the characteristic closure rate.

6) If the mutual gravitational interaction between a particle and an astronautical vehicle moving in a communal central force field is negligible, as viewed by the astronaut the relative approach path of the former is essentially confined to a surface defined by reasonable navigational system inputs.

7) Though generally a complex function of the signal amplitude, if the latter is very low the weighted mean acquisition range exhibits the idealized $1/\nu$th power dependence upon signal power, where ν has the same meaning as above.

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An Inertial Guidance System Field Test Program for a Ballistic Missile Weapon System*

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Summary—**A field test program for an inertial guidance system can easily extend from coast to coast and will require large numbers of experienced personnel and equipments. Included in the field test program are *Sled Tests*, *Captive Tests*, *Flight Test*, *Operational Tests* and *Contractor Liaison*. These areas of tests are described and objectives are reviewed and discussed.**

It is recognized that the actual use of a weapon system in its operational environment is the only conclusive test of that weapon system. However, an intelligently planned, integrated and executed test program can establish a high degree of confidence in the operational performance of a given system design. Therefore, a test program must be so planned and executed as to fully qualify a given system design.

The concept of a design verification program places extreme emphasis upon the following test concepts.

1) Dynamic operating tests on a system is the goal in all phases of the test program.
2) Primary emphasis is placed upon the testing of the most inclusive assembly available. For example, module testing is emphasized until components become available for test; then component testing is emphasized until systems become available for test, at which time the primary emphasis is shifted to system testing. Module and component testing are then carried on merely to complement system testing by further isolating malfunctions revealed in the more inclusive system tests.
3) Design verification is thoroughly integrated and is planned so that all phases of the test program complement and support each other.

The test program supplements the reliability program in determining component and system reliability using mean time to failure as a yardstick.

A complete test program outline includes the following:

- I. In Plant Tests
  - A. Engineering Tests
    - 1) Gyro and Accelerometer Study Program
    - 2) REAC Computer Analysis Program
    - 3) Breadboard Tests
    - 4) Product Improvement
  - B. Environmental Tests
    - 1) Verification Tests
    - 2) Flight Proofing Tests
    - 3) Evaluation Tests
    - 4) Qualification Tests
- II. Field Tests
  - A. Sled Tests
  - B. Contractor Liaison
  - C. Captive Tests
  - D. Flight Tests
  - E. Operational Tests

The general objectives that must be accomplished during each phase of the field tests follow.

SLED TESTS

During the entire R and D effort, a rocket sled test program will complement the environmental and flight proofing programs.

The sled environment provides jerk inputs which are difficult to obtain by other means. Sled testing also allows simultaneous operation of all axes of the inertial measurement unit during application of the combined acceleration-vibration environment of the sled. This allows evaluation of interaction or cross-coupling among the inertial measurement units axes.

Prior to the first flight test of a complete guidance system, the sled test will have demonstrated system operation in a combined acceleration and vibration environment, complementing the in-plant flight-proofing program.

Information obtained from the sled tests during this phase is much more comprehensive than the information obtained from the early missile flights. This greater capability is accomplished by provision for telemetering a greater number of signals and almost unlimited flexibility in choice of information to be monitored. Recoverability of the equipment used on sled tests and subsequent evaluation provide valuable information not easily obtainable by other methods.

The main phases of a sled test program are now listed in chronological order.

Evaluation of Sled Environment

This phase obtains sled environment information while checking out the basic sled equipment and familiarizing personnel with test procedures. The suitability of sled-borne power supplies and of equipment mounting brackets are demonstrated.

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* Original manuscript received by the IRE; December 22, 1959.
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Evaluation of Signal Conditioner Component and Telemetry

The signal conditioner and telemetry stability in the severe sled environment are demonstrated. The reliability and mechanical integrity of the conditioner and telemetry are demonstrated.

Accelerometer Assembly Tests

The effect of the sled environment on various accelerometer constants is evaluated. In addition, the associated instrumentation, recording and data reduction techniques are evaluated during these tests.

Qualitative Erection and Stabilization Tests

This phase demonstrates functional operation of the equipment and the applicable portion of the countdown procedures are evaluated.

Velocity Measurement Tests

Correlation of system and velocity measurement is the objective of this phase. Velocity measurement errors and stabilization errors are isolated.

Qualitative System Tests

The complete system is functionally demonstrated during this phase. The complete countdown procedure is evaluated.

Quantitative System Evaluation

This phase consists of running test problems which are used to accomplish cutoff or other signals demonstrating computer operation.

Flight Support Tests

Areas indicated for critical evaluation by flight test results are investigated. These tests can take priority over others at any time if the flight test program is in progress.

Marginal Conditions Tests

The effects of non-nominal calibrations and/or power supplies are investigated. Included in these tests are the effects of power supply transients on the system operation.

CONTRACTOR LIAISON

In order to accomplish the over-all objectives of a successful weapon system, a great need exists for a coordinated effort during the entire test program by all the contractors concerned. In line with this objective, the associate contractor must plan to have a sound engineering group located at the air frame contractor's facility.

The airframe contractor activities which require support will include the following areas:

a) Missile engineering tests (integration tests)
b) Acceptance tests
    1) Receiving and inspection
    2) Installation and acceptance testing
c) Captive tests
d) Laboratory
    The lab will support acceptance tests, missile engineering tests and captive tests.

Integration Tests

Missile engineering tests will consist of laboratory tests of the integration of the guidance equipment into the missile system. The basic compatibility tests must be completed before commencement of the flight test program.

The primary objective of the missile engineering test program is to evaluate compatibility, functional integration tests, and engineering evaluation tests of the guidance set, missile, and missile subsystems.

Specific test objectives are:

1) Verify that the system physically can be installed into the missile.
2) Demonstrate the compatibility of the ground support equipment with the missile.
3) Demonstrate the compatibility of the inertial guidance set with other subsystems.
4) Evaluate the system operation with missile power supplies.
5) Evaluate the effects of power transfer and power transients on system operation.
6) Evaluate system performance with the missile cabling and power to verify that ground loops do not exist and noise levels and interference from other subsystems do not affect guidance system operation.

Acceptance Testing

Following a complete inertial guidance set calibration, functional tests, and acceptance at the contractor plant, inertial guidance sets will be transported to the airframe manufacturer for inspection, checkout, installation, and missile acceptance checks.

Captive Tests

Static firings of complete missiles are accomplished by the airframe contractor at a captive test facility. Captive tests can be accomplished in two ways. They can be accomplished with the static firing of production missiles after complete functional integration tests have been completed, or a test program can be implemented that will static fire one or several missiles many times.

The tests are designed primarily to increase confidence in launches and to improve reliability. The later tests accomplish this over a shorter period of time. The former program is better as the configuration of the missile changes, and the captive test is an immediate positive test of that configuration.

FLIGHT TEST PROGRAM

The ultimate design verification and weapon system evaluation can be obtained only from the results of flight tests. In view of this, a strong and early program must be planned.

The important phase of the flight test program will sequentially accomplish the following objectives:

1) Permit any design modification dictated by flight test data to be accomplished prior to an extensive production effort toward operational equipment.
2) Provide actual environment data, making possible a review of the environments assumed for purpose of design.
3) Demonstrate the mutual compatibility of the operation and function of the inertial guidance equipment under actual operational conditions.
4) Make possible the evaluation of the operation and function of the equipment under actual operation conditions.
5) Demonstrate the capability of the weapon system, and its subsystems, to perform the mission for which it is intended.

In general, flight tests evaluate the ability of the inertial guidance equipment to guide the missile to the cutoff point to effect the required ballistic trajectory. Passenger flights of components can in many cases provide a quantitative and qualitative evaluation of the components prior to actual inertially guided flight tests. Passive flights are not required if early passenger flights, laboratory, sled, flight proofing and other environmental testing are accomplished prior to system flight testing.

Airborne instrumentation must be complete enough so that performance and accuracy data will be obtained on any flight. Accuracy should be an objective of every flight commencing with the first flight. Power supply data should be available on all flights throughout the program to insure proper interpretation of flight data.

The primary intent of the flight tests is to determine the accuracy and the operating characteristics of the inertial guidance set during missile flight. The operating environment of the inertial guidance equipment is determined on several of the early flights.

Data obtained from each flight is analyzed, and the results are transmitted to the design engineers for reevaluation of the individual assemblies.

Specific flight test objectives.

1) Compatibility of the ground support equipment, missile, launch area and inertial guidance system.
2) Ability of the stabilization servo loops to isolate the inertial package from the base motion under dynamic conditions.
3) Accuracy of the accelerometer loops under dynamic conditions.
4) Accuracy of the computing elements in generating the correct steering, engine cutoff and prearm signals from the measured accelerations and the stored or programmed data inputs.
5) The accuracy, stability, reliability, performance, etc., of the power supplies before and during powered flight.
6) Accuracy of the inertial guidance system, based on a comparison of velocity data and external data determination of missile position throughout the flight profile and at the time of cutoff.
7) Determination of the operating environment.
8) General functional operation of erection and ground support equipment under field conditions.
9) Verification of computer operation, computer coefficients and other launcher-target parameters.
10) Evaluation of the staging transients and their effect on the operation of the inertial guidance set.

As the test program progresses, situations will arise which will show a need for additions or alterations to flight objectives. The program must be flexible so that the changes in objectives will be a simple matter. The associated equipment, such as the signal conditioner, must allow for immediate changes in telemetry channel assignment, if required in accordance with changes of objectives.

OPERATIONAL TESTS

It is recognized that the actual use of a weapon system in its operational environment is the only conclusive test of a weapon system. It is the intent of the operational tests to approach this environment as closely as possible.

The purpose of the operational tests is to demonstrate the existence of an operational weapon system. As many as possible of the events involved in the complete factory-to-launch sequence are tested. The primary objectives of the program are as follows:

1) Compatibility checks between the missile, ground support equipment and the operational missile launcher.
2) Evaluation of the ability of the handling and/or transportation and installation equipment to perform its task properly with adequate protection, ease, safety for the operating personnel, and with maximum efficiency in an operational environment.
3) Evaluation of the periodic checkout equipment, and procedures to ascertain its ability to verify that the weapon system is in the required state of readiness.
4) Evaluation of the operational countdown procedure and investigation of the possibility of decreasing the readiness time.
5) Evaluation of the procedure and time required for removal and installation of an inertial guidance set

and to return the missile to readiness condition.

6) Evaluation of launches which are accomplished by operational personnel and procedures.

Conclusion

It can be seen from the test program presented above that a large part of a complete test program must be accomplished in the field. This results in an extensive field test program that can extend from one end of the country to the other and also requires considerable numbers of experienced personnel and equipment. There are areas included in the field testing program which apparently could be adequately evaluated in the contractor's plant. Admittedly, there are portions of these areas that can be evaluated in the plant, and it is quite possible that they would receive a better evaluation there because of the high grade of personnel and facilities available. However, to make a completely thorough evaluation, field testing is still required. There are several reasons why extensive field testing is absolutely essential. Probably the most significant reason is that the exact operational conditions cannot be duplicated in the contractor's plant and the only conclusive test is the actual use of the weapon system in its operational environment.

A Pragmatic Approach to Space Communication*

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Summary—**Examination of the fundamental limitations on modulation efficiency and present state-of-the-art practices in transmitter design, solar cell power sources, receiver design and antenna design shows that communication with large information rates is possible throughout the solar system but that practical interstellar communication is not now feasible. Two representative telemetry systems are discussed, the FM/PM analog Microlock system and the digital Telebit system.**

Introduction

THE paper which follows attempts to establish the realistic limits which the state of the art of present day components places upon the transmission of information from space vehicles.

The fundamental problem of space communication is effective energy; that is, the energy necessary to transmit the required information over the distances characteristic of the various space missions. More specifically, it is the ratio of the thermal energy in the bandwidth required to transmit the desired information per unit time to the effective transmitted energy. Thus, the fundamental parameter of space communications is the energy per bit of information, and the fundamental limitation is ultimately that of the effective energy or the effective power of the system.

This basic limitation can be divided into two classes of problems. The first is the generation, transmission, and reception of energy. The second is determining the most effective method of modulating this energy to transmit the required information.

The information is determined by the particular space mission and the requirements of the experiments or experimenters. The rate of transmission of information is determined by the amount of data processing which is carried out in the satellite itself. Thus, the power in low-altitude earth satellites is sufficiently high and the distance is small enough so that sophistication in either modulation techniques or in data processing within the satellite is not essential. On the other hand, the extremely narrow bandwidth characteristic of interstellar probes requires a very highly sophisticated data processing in the satellite itself if appreciable information is to be transmitted from the experiments. From another aspect, the rapid motion of low-altitude earth satellites requires ground antennas of low directivity and a very large number of ground stations if continuous coverage is to be achieved. At the other extreme, high-altitude satellites for lunar probes or interplanetary probes require no more than three ground antennas for complete coverage, and since the motion of the satellite relative to the earth's surface is slow, these antennas can be very large.

Despite the wide variety of problems associated with each of the space missions, a broader view shows that available components impose a common limitation affecting each type of service. Thus, the power supply,

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* Original manuscript received by the IRE, December 2, 1959. Portions of the material in this paper have been presented at the 1959 Western Electronic Show and Convention, San Francisco Cow Palace, San Francisco, Calif., August 20, 1959, and the Fifth Annual Radar Symposium, Willow Run Labs., University of Michigan, Ann Arbor, January 27, 1959.

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the power amplifier, temperature control, the antennas, both in the air and on the ground, and the initial stages of the receiver on the ground are critical energy-determining components. In addition, there is the limitation on the efficiency of the modulation system imposed by available coding and decoding techniques. However, since the characteristics of these components and techniques are known, it is possible to trade off the component characteristic, the method of modulation, and the requirements of data processing to design an optimum system for any particular mission.

The following sections will outline the parameters involved in energy transmission, the problems associated with the encoding and transmission of information, and will apply these results to four representative space missions.

ENERGY

As far as space communication is concerned, the problem of providing sufficient energy may be divided between the amount of energy available in the space vehicle, the degree to which that energy can be directed toward the ground receiver, and the efficiency of the receiving system in detecting this energy in the presence of noise.

Satellite Transmitting System

In the space vehicle, both the transmitted power and the total available energy are the important communication parameters. The effective power available from the space vehicle may be increased, 1) by increasing the transmitter power, 2) by increasing the transmitter efficiency, or 3) by increasing the antenna gain.

To increase transmitter power, it is necessary to provide a larger energy source, larger components, and heavier and more complex temperature control mechanisms. All of this results in an almost linear increase in payload weight with increasing power. The energy supply may be chemical, thermal, or nuclear in origin. The most efficient sources of chemical energy in terms of watt-hours per pound appear to be, at the present time, the various forms of the silver cadmium cells. Since this energy lies between 35 and 50 watt-hours per pound, the use of these cells as the primary source of energy for space vehicles is severely limited.

For earth and interplanetary satellites, it is possible to make use of the thermal energy of the sun, either by means of solar cells or thermocouples to provide a source of energy of relatively low-power capability but of very large total magnitude. At the present state of the art, it is apparent that for vehicles having lifetimes greater than two days, the solar cell is superior to a chemical battery in terms of weight for a given total energy.

Nuclear sources of electrical energy are in a very early stage of development, and it is not possible at this time to define precisely the energy per pound that will be available when their development is complete. Early estimates indicate some tens of kilowatt-hours per pound as being available. For missions far from the sun, such as flights to Pluto or to interstellar space, it appears that nuclear fission sources of energy are the only practical sources likely to be available within the next ten years.

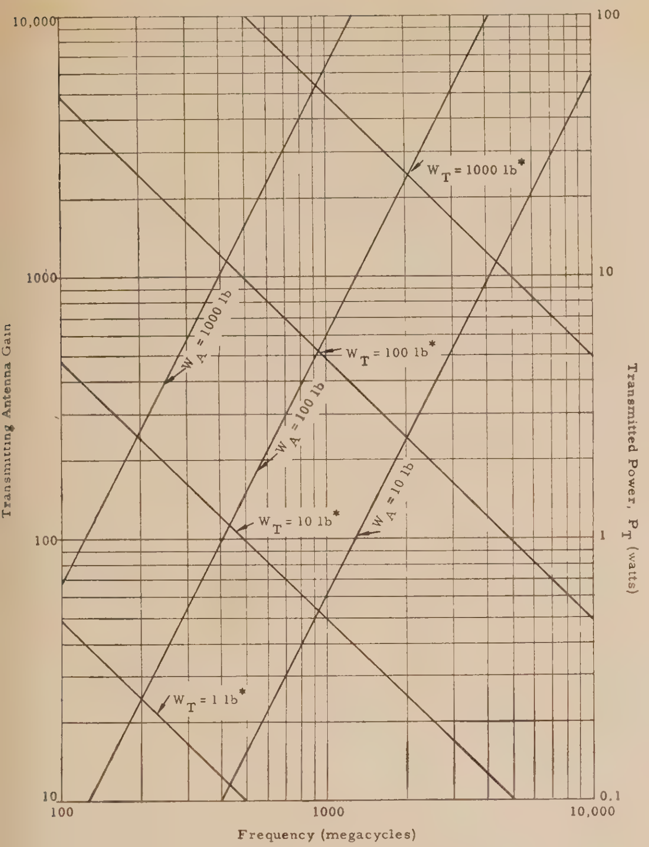
Another problem to be considered is the efficiency with which this energy is converted into radio waves. At the present time it appears possible to achieve efficiencies between 50 and 80 per cent for transmitters below 1000 megacycles, and efficiencies on the order of 10 to 50 per cent for transmitters above 1000 megacycles. Moreover, since radio transmitters have been studied for a long period of time, major improvements in the operating efficiency are unlikely. The unused energy is heat and must be dissipated if the transmitter is not to be destroyed. Although the heat that can be radiated from the surface of the space vehicle depends upon its orientation with respect to the sun, for areas which are not exposed to direct radiation from planets or from the sun, it is possible to dissipate passively more than 300 watts per square foot.

Two factors then limit the amount of power that can be generated and transmitted from the space vehicle. First, the energy available, which is dependent upon the weight that can be allocated to the energy source, and the heat energy which can be dissipated. This depends in part upon the area available, that is, the size of the space vehicle, and upon the weight which can be allocated.

The effective power transmitted depends, in addition, upon the directivity of the transmitting antenna, and here two problems must be recognized. On the one hand, although the available effective power can be increased tremendously by the use of directive vehicle antennas, such antennas presuppose an ability to control the attitude of the space vehicle. On the other hand, it is generally desirable to provide failure instrumentation for space vehicles so that, if an element of the system fails, it is possible to determine the cause of the failure. For this purpose, it is desirable to have an omnidirectional vehicle antenna. It is probable that future space vehicles will use omnidirectional antennas for minimum tracking and failure instrumentation, and directional antennas for the primary transmission of information.

An empirical relation was derived from present experience with high-frequency components which leads to the parametric relations shown in Fig. 1 between the gain, weight and frequency of parabolic antennas, and between the power, weight and frequency of the transmitter system including an omnidirectional solar cell power supply and temperature control equipment.

Essentially these curves are statements of the fact that the antenna gain is proportional to the square of the diameter in wavelengths and the weight of an antenna is proportional to its area, and that the weight of the power supply and of the heat sink increases with frequency since the efficiency of available transmitters decreases with increasing frequency.



* **Transmitter weight includes power supply and temperature control equipment.**

Fig. 1—Airborne antenna gain for three antenna weights, W_A, and transmitted power, P_T, for four transmitter weights, both as a function of frequency.

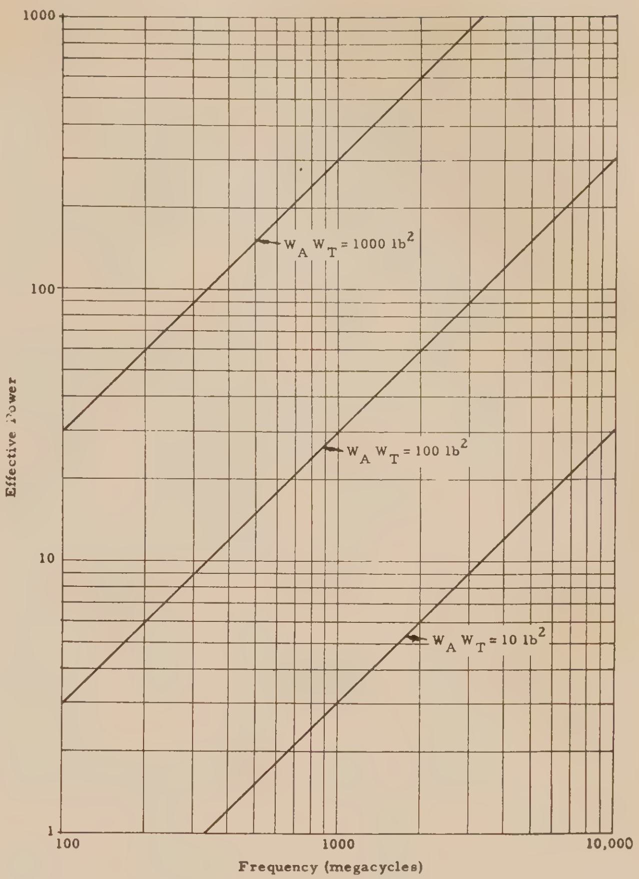


Fig. 2—Effective radiated power as a function of frequency for three given weights to be allocated to transmitting antennas and transmitters.

Multiplying the transmitted power by the antenna gain gives the effective radiated power, which is plotted as a function of frequency in Fig. 2. The parameter here is the product of the weight allocated to the antenna system and the weight of the transmitter and its power supply. The curves are derived from

$$\text{Effective Power} = P_T\,G \approx 0.3\,\frac{W_A W_T}{\lambda} \tag{1}$$

where

P_T = the transmitted power,
G = the antenna gain,
W_A = the weight of the antenna,
W_T = the weight of the transmitter and power supply, and
λ = the wavelength in feet.

Regardless of the constant, which varies from system to system, it is apparent from the form of the equation that an optimum division of weight would make the antenna system weight equal to that of the transmitter system. It is also apparent where directive antennas are used that, over this range of frequencies, the higher the frequency the greater the effective transmitted power. It must be noted, however, that this simplified analysis has not taken into account the increased problems associated with attitude control as the antenna bandwidth narrows, nor the increased mechanical tolerance at high frequencies. These are important as one approaches 10,000 mc, and, at such frequencies, the curves are no longer valid.

In the case of failure instrumentation where a nondirective satellite antenna is desirable, the curves of transmitter power vs frequency of Fig. 1 apply, and it is evident that the lower the transmitting frequency the lighter the system is. However, as is shown in the next section, galactic noise limits the lowest permissible frequency for space communication to the order of 400 mc.

The Ground Receiving System

The receiving system may be improved either by increasing the receiving antenna area or by decreasing the effective noise temperatures in the input circuits of the receiver. If the receiving system is mounted on the earth, then even with the best of maser preamplifiers, the input noise temperature is limited to 50°K due to the antenna radiation characteristics (see Fig. 3). Therefore, for ground-based antennas, no real improvement in input noise appears practical.

However, if the receiving antenna is in space, then it is possible to achieve an input noise temperature which is limited only by the galactic background noise and the inherent characteristic of either maser or parametric amplifiers. With such antennas, it appears that an effective noise temperature on the order of 1°K is possible and that as techniques for the maser preamplifiers are developed even lower temperatures may be achieved. The variation of these limitations with frequencies are shown in Fig. 4.

The remaining system parameter which may be varied is the effective area of the receiving antenna. The following paragraphs show that the steerable parabolic reflecting antenna is the most practical design for ground-based antennas. This type of antenna has been built in sizes up to 250 feet in diameter, and studies have been made indicating that sizes up to 600 feet are feasible. However, for diameters larger than about 250 feet, it is necessary to introduce an elaborate servocontrol system for adjusting the individual subpanels as a functioy of the antenna elevation angle and wind loading. Thus, there is a point at about 250 feet beyond which there is a relatively sharp increase in mechanical complexity and cost.

To investigate the effect of increasing antenna size, one can employ the usual formula for power received as a function of power transmitted. This equation is

$$P_R = kTBn\left(\frac{S}{N}\right) = \frac{(P_T G_T) A_R \epsilon}{4\pi R^2 l} \tag{2}$$

where

$B = 10$ cps = bandwidth,
$n = 2.0$ db = noise figure of receiver,
$S/N = 10$ db = required signal-to-noise ratio,
$\epsilon = \approx 0.5$ = antenna efficiency,
$kT = 1.3 \times 10^{-23} \times 300 \cong 4 \times 10^{-21}$,
G_T = vehicle antenna gain,
P_T = vehicle transmitter power,
$R = 50{,}000{,}000$ miles $= 3 \times 10^{11}$ feet = range,
$A_R = \pi D^2/4$ = antenna collection area (D diameter), and
l = 6-db loss from polarization, cables, etc.

The figures chosen are representative of those attainable in extreme range space communication systems. One will note that the bandwidth, 10 cps, is relatively narrow compared with that of the usual earth-type communication systems. The noise figure of the receiver is representative of current good practice in receivers in the 100- to 400-mc range. This figure does not represent noise figures attainable using parametric or maser amplifiers which are discussed later. A signal-to-noise ratio of 10 db is quite low, since this signal-to-noise ratio must be adequate for acquiring after search as well as for tracking once the signal has been found; in fact, a 20-db signal-to-noise ratio would be desirable. The ground antenna efficiency of 0.5 leaves some margin for sidelobe control. Vehicle antenna gain and vehicle transmitter power are treated, as they in fact are, as functions of each other (see Fig. 2). The 6-db losses are conservative, but reasonable, assumptions.

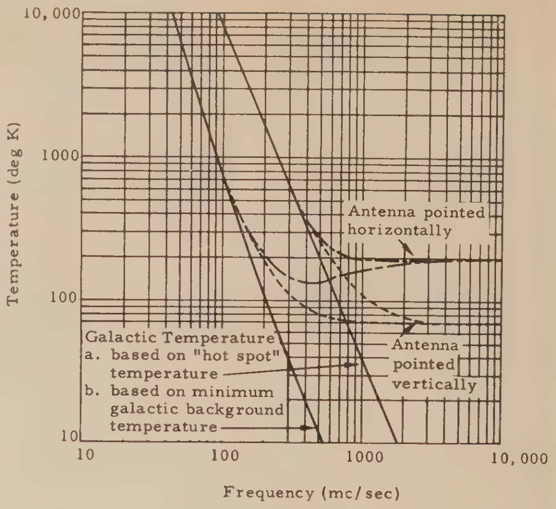


Fig. 3—Equivalent antenna temperatures including galactic background, atmospheric attenuation, and antenna sidelobes. (Assumes an aperture efficiency of 0.5, that half the sidelobes' energy is received from the ground, which is assumed to be a blackbody at 280°K.)

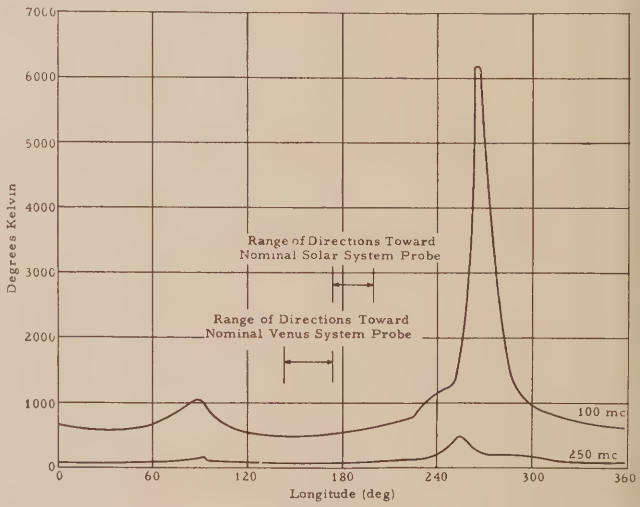


Fig. 4—Cosmic radio noise in degrees Kelvin in the ecliptic as a function of longitude (measured east from the vernal equinox).

The range chosen, 50,000,000 miles, is not the range to any particular point in space, but it is representative of ranges from the earth to interplanetary vehicles on their outward journey. It does not represent, for instance, the maximum that one might encounter if an attempt were made to follow the vehicle over a complete circuit about the sun.

Solving (1) then for D, the antenna diameter, one obtains

$$D = 4R\left[\frac{lkTBn(S/N)}{(P_T G_T)\epsilon}\right]^{1/2}. \tag{3}$$

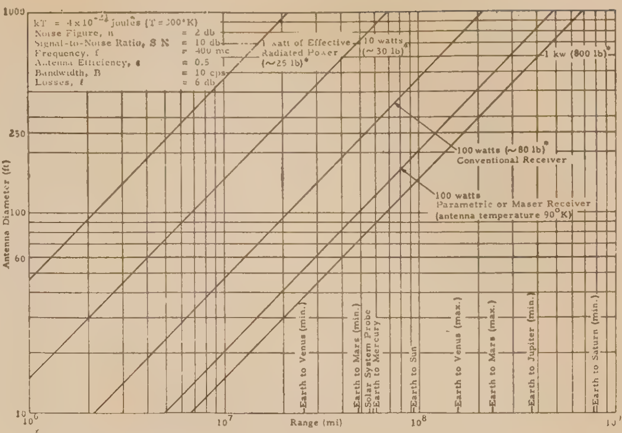
One interesting fact, apparent at once, is that the antenna diameter required is directly proportional to range. Using the numbers assumed above in (2), one obtains a required antenna diameter of about 250 feet. It is obvious from the square-root relationship that any reasonable variation in all parameters except range will have only a moderate effect upon the required antenna diameter.

As another illustration of this relationship, the JPL Microlock receiver and a 250-foot ground antenna would receive a usable signal of 10-cycle bandwidth with an effective radiated power of 100 watts in orbit about Venus at about 55,000,000 miles. The transmitter would weigh about 15 pounds. Optimum solar cells and batteries would weigh about 50 pounds, assuming a 10 per cent duty cycle. To use a 60-foot antenna would require either 1000 watts of effective radiated power or a parametric or a maser preamplifier with a 200-watt transmitter, or the bandwidth would have to be reduced to 0.5 cps.

Fig. 5 illustrates the effect of range upon the ground antenna size for various effective radiated powers from the vehicle. This figure assumes a bandwidth of 10 cps, a signal-to-noise ratio of 10 db, a receiver noise figure of 2 db, and losses of 6 db. It shows that at 55,000,000 miles 100 watts of radiated power with a 250-foot antenna is just satisfactory.

Fig. 6 shows the required antenna diameter as a function of the range to the vehicle with three different ground receivers. A 100-watt transmitter with a conventional ground receiver can give a 10-db signal-to-noise ratio at 55,000,000 miles, using a 250-foot antenna. However, if a parametric or maser receiver (with an antenna temperature of 70°K) is used, a 100-watt transmitter can provide a usable signal at 120,000,000 miles. If the frequency is increased to 1100 mc, the range can be increased to 135,000,000 miles. Although parametric amplifiers and maser noise temperatures of less than 30°K are possible, the limiting noise will be determined principally by antenna temperature, as has been shown in Fig. 3. Fig. 6 again illustrates the principle that a great deal can be gained by improving the ground system—gains which become a permanent part of the system.

A more direct improvement is the use of variable receiver polarization. This is dependent on a knowledge or measurement of the plane of polarization of the received signal, but with relatively simple equipment, it will produce a 3-db increase in signal-to-noise ratio.



* Transmitter weights include power supply for 10 per cent duty cycle.

Fig. 5—Antenna diameter as a function of range for a number of transmitters.

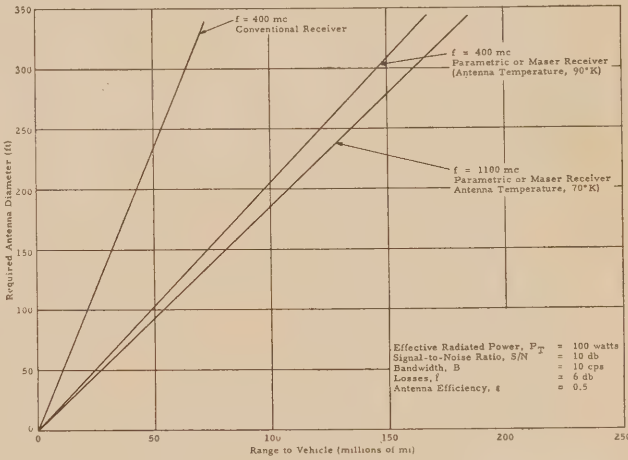


Fig. 6—Antenna diameter as a function of range for a conventional receiver and a maser receiver at two frequencies.

Figs. 7–9 are cross plots of Fig. 5 (with different parameters varied). Fig. 7 shows the signal-to-noise ratio as a function of range of the vehicle for a number of antenna sizes. Fig. 8 shows the bandwidth as a function of range to the vehicle for a number of antenna sizes. Fig. 9 shows transmitted power requirements as a function of range to the vehicle for a number of antenna sizes.

Each of these figures shows the great gains that are made by increasing the antenna diamter. In particular, Fig. 9 shows that almost 1600 watts of radiated power are required to transmit 55,000,000 miles from the vehicle to a 60-foot ground antenna with a signal-to-noise ratio of 10 db. If a 250-foot antenna is used, only 100 watts are required.

In connection with Fig. 7, it should again be emphasized that a signal-to-noise ratio of less than 10 db is not satisfactory since that ratio or more is desirable for acquisition.

The parameters used above are not all representative

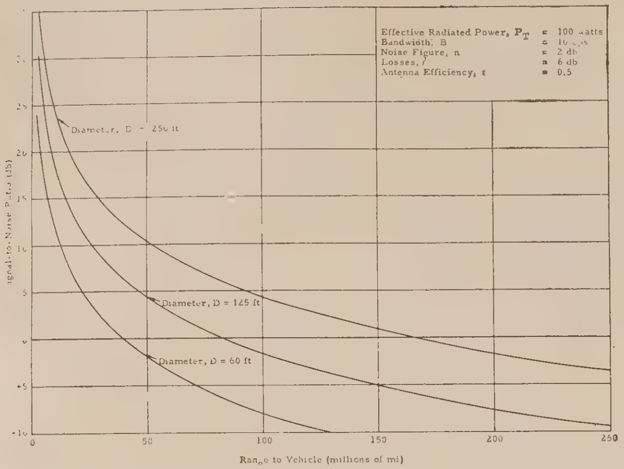


Fig. 7—Signal-to-noise ratio as a function of range for three ground antenna sizes.

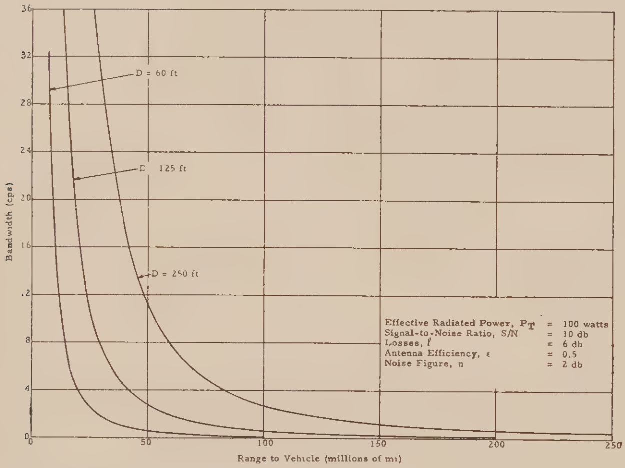


Fig. 8—Bandwidth as a function of range for three ground antenna sizes.

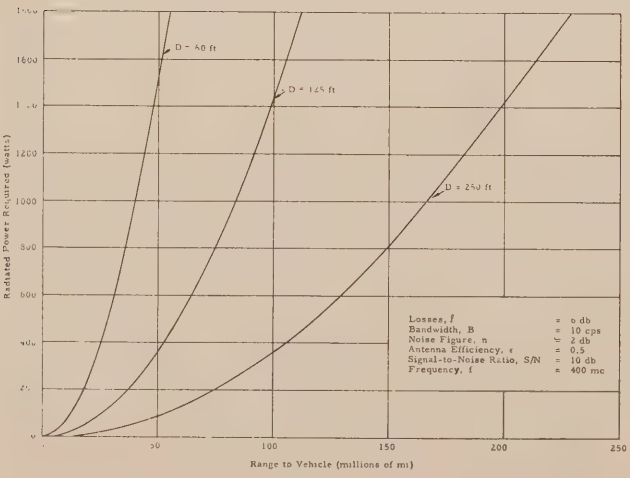


Fig. 9—Airborne transmitted power as a function of range for three ground antenna sizes.

of what one might ultimately desire in a space communication system. For instance, it seems reasonable that we would ultimately wish to transmit facsimile pictures with bandwidths of hundreds of thousands of cycles or possibly even TV pictures with bandwidths which exceed a megacycle. Manned space flights will require, as an absolute minimum, a continuous voice channel of at least telephone quality. For a continuous voice-communication capability independent of vehicle attitude, 500 watts of continuous power drain, which is near the optimum for 100 watts of effective radiated power from a communication transmitter at 400 mc, is necessary. This is a considerable drain on a space power supply. It is apparent that to achieve large bandwidths at long distances requires, in addition to the use of large ground antennas, improvement in all elements of the communication system.

To determine the type of ground antenna, the approximate operating frequency must first be established. An examination of presently available transmitters, of the uncertainty concerning the operating frequency of low-noise maser amplifiers, and of the rate of development of efficient microwave transmitting tubes, clearly underscores the necessity for an antenna capable of operating over a wide range of frequencies. Since multielement antenna arrays with a large effective collecting area are essentially fixed frequency devices, it appears that the frequency insensitive reflector antenna is better. Moreover, since the space vehicles will have to be tracked over large angles and since antenna arrays are essentially fixed in direction, the steerable parabolic dish is the only choice which satisfies all the requirements.

As the physical size is increased, the efficiency of the capture area must be maintained. However, to maintain area efficiency, the physical tolerances must be maintained to about $\frac{1}{16}$ of a wavelength to focus the received energy into the feed. Thus, if the wavelength is one foot and the antenna is 500 feet in diameter, the tolerances would be about one part in 10^4, or a $\frac{1}{2}$-inch total deflection. Despite these complex engineering problems, very large antennas have been built (Fig. 10 shows the 250-foot radio telescope near Manchester, England) and many more are contemplated.

Given only initial specifications as to sky coverage, antenna size, shape, and accuracy, every group that has studied large antennas has come up with essentially the same design; that is, a merry-go-round or azimuth tracking stand upon which is mounted an antenna on a horizontal axis so that the elevation angle can be varied. This is substantially the design evolved at Manchester for the Jodrell Bank antenna.

The only existing antenna suitable for interplanetary space communications, the 250-foot British antenna at Jodrell Bank, England, is used in the only world-wide tracking network in the world today, the space navigation network (SpaN-Net) of STL/BMD. This antenna has demonstrated, during the Able[1] flights, the value of

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[1] Pioneer I and II, Explorer VI.

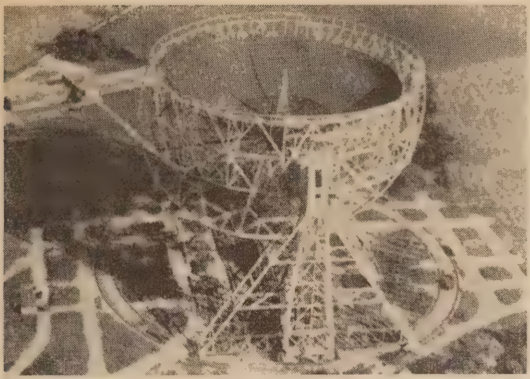

Fig. 10—The radio telescope near Manchester, England.

large antennas. However, because it is located about 55 degrees north of the equator, its coverage of the plane of the ecliptic is not optimum. In addition, since it is the only existing at present, the coverage of any given point in space is limited by the rotation of the earth.

INFORMATION ENCODING AND TRANSMISSION

In a communication system, the kind and amount of information to be transmitted is of first importance. The kind of information depends in large measure upon the source and, as the following examples indicate, it may be varied by proper selection of the form of the message generated. The amount of information must be tailored to the channel capacity of the communications system and, for many scientific purposes, may be varied without much loss in the utility of the experiment. For instance, the size of the diaphragm on an impact-sensing micrometeorite detector may be reduced until the number of impulses per second is adjusted to the available bandwidth. Or, in the case of a scintillation or Geiger counter, appropriate scalers may be inserted so that the final output counting rate is a small, but known, fraction of the input rate. This type of system has, in addition, the possibility of easily varying the output rate by switching the number of divider stages. In case there is a requirement for transmitting pictures, the effective bandwidth and information rate may be reduced by sampling techniques.

Another kind of information is obtained from the various equipment performance monitors in the vehicle. Since the information rate from these monitors is usually very low, it is possible by subcommutating to transmit a very large number of measurements over a very narrow bandwidth. Thus, it is possible by relatively simple means to adjust the information rate for physical measurements to the available channel capacity of a space communication system. However, for such information as real time voice channels there is only a limited possibility of reducing the bandwidth even though the information rate for this service is small, since there is a real limitation on the efficiency of encoding represented by our vocal cords. Since voice or video transmission characteristics are not easily modified, and since the weight limitation on equipment is likely to persist for some time to come in space vehicles, the probability of achieving real time voice or video communications at interplanetary distances is rather low.

Basically, space communication suffers from trying to achieve two mutually incompatible objectives. On the one hand, there is the desire to transmit as much information as possible. On the other hand, there is the necessity to conserve weight with the resultant fundamental limitation on transmission time and information rate. As was shown in Fig. 9, the bandwidth is extremely limited even at fairly short interplanetary distances and for very large ground antennas. This limitation upon bandwidth sets the channel capacity, and thus the information rate which can be transmitted. Fig. 9 also demonstrates that an essential characteristic of a space communication system should be flexibility in bandwidth, so that when the vehicle is at close ranges, its bandwidth can be large, while at long ranges its bandwidth may be narrowed.

The method of modulation establishes the efficiency of the communications system. As Hartley and Shannon[2] have shown, there is a maximum amount of information which can be transmitted through a channel of given bandwidth and signal-to-noise ratio. Thus

$$H = B_M \log_2\left(1 + \frac{S}{N}\right) \tag{4}$$

where

H = the information rate in bits per second,
B_M = the bandwidth of the message channel,
S = the signal, and
N = the noise in the bandwidth B_M.

Furthermore, it is important to note that the effective signal-to-noise ratio in the message channel is a function of the ratio of the transmission channel bandwidth B_T, to the message channel bandwidth and in the ideal case approaches

$$\left(\frac{S}{N}\right) B_T = \left(\frac{S'}{N'}\right) B_M. \tag{5}$$

There is a wide variation in the ability of modulation systems to approach the ideal. Thus, in the conventional FM broadcast system,

$$\left(\frac{S}{N}\right) = \left(\frac{S'}{N'}\right) \frac{B_M}{B_T} \tag{6}$$

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[2] R. V. L. Hartley, "Transmission of information," *Bell Sys. Tech. J.*, vol. 7, p. 535; July, 1928; and C. E. Shannon, "A mathematical theory of communication," *Bell Sys. Tech. J.*, vol. 27, pp. 379–423, 623–656, July/October, 1948.

and although the noise improvement in the output is real, it falls far short of the Shannon limits.

A comparison of the various modulation methods results in the conclusion that for space communications the most efficient system is probably some form of pulse code modulation, both from the standpoint of encoding and decoding, and from the standpoint of modulation efficiency. For purposes of illustration two forms of modulation adapted to space communications will be described and compared.

In the Pioneer series of lunar satellites, an FM/PM analog telemetry system developed by Jet Propulsion Laboratories was used.[3] This "Microlock" system uses a phase-locked receiver to achieve a lock-on sensitivity of −150 dbm with a 10-cycle locked-loop bandwidth. There are six subcarriers with a theoretical modulation bandwidth of 0.8 cps, although in practice, because of subcarrier drift and the dynamic characteristics of the subcarrier discriminators, they have a realizable information bandwidth of only about 1/100 cps. As was demonstrated, this system has the necessary sensitivity to operate to lunar distances with a transmitted power of about 100 mw. The combined total information rate for the six channels is about the equivalent of 0.5 bit per second. The limiting characteristics of this system are:

1) the information bandwidth is fixed;
2) the practically achievable channel efficiency is low;
3) since the system is not quantized, it suffers degradation on retransmission or rerecording; and
4) the information must be transmitted in real time.

In an attempt to improve the system, a digital telemetry system called "Telebit" was developed which will, at lunar distances and the same 100-mw power, permit the transmission of 8 bits of information per second, or, on command and for transmission at greater or lesser distances, will change power and transmit either 1 bit or 64 bits per second. In addition, with airborne analog-to-digital converters, the information is quantized and digitalized, so that once a message is received, it will not be degraded by retransmission over communication links to the central station. The Telebit system provides, in addition, a transistor memory for storing the output of the experiments, so that intermittent transmission of the data is possible.

A quantitative comparison of the Pioneer I and II Microlock and the Telebit system with the ideal communications system described by Shannon[4] leads to the following expressions:

$$\beta = \left(\frac{S}{N}\right)\frac{B}{H} \tag{7}$$

where β is a figure of merit based on Shannon's theorem, (4); for an ideal system where the transmission channel bandwidth is infinite, the figure of merit

$$\beta_0 = 0.693;$$

for the case of the Microlock system used in Pioneer I and II

$$\beta = 43.5,$$

or

$$\beta/\beta_0 = 18 \text{ db};$$

while for the Telebit system

$$\beta = 4.5,$$

or

$$\beta/\beta_0 = 8 \text{ db}.$$

It is interesting to note that this latter figure is nearly as good as the best quantized system described by Saunders[5] for this bit level and appears to approach the best physically realizable modulation system.

Since the Telebit system has not been described elsewhere a brief description follows. Basically, Telebit is a digital telemetry system which provides for transmission of information from space probes to the ground and presents the information in a partially processed form. The payload portion of the Telebit system accepts information from both analog and digital experiments and processes this information until it is in a form suitable for transmission. The ground portion of the Telebit system consists of several stations located throughout the world and a central processing station for rapid processing and presentation. The payload portion of the Telebit system permits accumulation of information during periods between transmissions. It also commutates several types of input information so as to produce a time-multiplexed train of pulses containing information about a variety of experiments.

The Telebit system accepts two kinds of inputs from the experiments. The first consists of information in the form of the occurrence of an event or events, such as micrometeorites and radiation particle impingement. The second class consists of analog inputs where the variable to be measured is a continuous function of time.

Power considerations set bounds on the time during which information can be transmitted to the ground and upon the period between such transmissions during which batteries are recharged. Sufficient time exists during each allowable transmission period to permit a read-out of each primary experiment two or three times. The Telebit system has been designed with the intent of optimizing information accumulated during transmitter OFF times while permitting maximum information transmission during the brief ON times. A careful review of high-energy particle experiments, for instance, indicated that 10 primary digits would adequately accumulate the number of events during a transmitter ON time.

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[3] "A Coherent Minimum Power Lunar Probe Telemetry System," Jet Propulsion Labs., Calif. Inst. Tech., Pasadena, Calif., external publication No. 610; August 12, 1959.

[4] Shannon, *op. cit.*, p. 654.

[5] R. W. Sanders, "Digilock Telemetry System," 1959 National Symposium on Telemetering, San Francisco, Calif., September 28–30, 1959.

Analog information does not directly lend itself to any simple means of accumulation. The experimenter must thus be content with obtaining analog information only during transmitter ON periods. Provision has been made, however, in some experiments, to provide for changes of scale as a function of the quantity being measured. An analysis of the accuracy with which analog information is obtained indicates that most primary experiments could be adequately described by six bits while some secondary experiments can be characterized by four bits. By grouping a six-bit experiment with a four-bit experiment, a word of 10 bits is derived. Conversion of the analog data to digital form is accomplished in an analog-to-digital converter which makes use of a 64-level digital ramp.

In addition to its function of accumulation and analog-to-digital conversion, the Telebit system commutates the successive experiments and thus derives a sequence of pulses which in groups characterize these experiments. The information conveyed during each commutated segment is called a "word" and the sequence of all words is called a "frame." While the number of pulses which comprise a word could take any value, a Telebit word is composed of 10 information pulses. Similarly, the number of words which compose a frame is determined by the number of experiments. The Telebit system includes 10 information words.

In addition to the information pulses of each word and the information words of each frame, synchronizing symbols are inserted to ease the decommutation problem on the ground. Two synchronizing pulses always having the same form are added to each word and one synchronizing word is added to the set of each frame. Thus, an entire word consists of 12 pulses and an entire frame of 11 words.

Inasmuch as it is desirable to vary the information transmission rate as the range to the payload changes, three pulse rates were provided, 1, 8, or 64 per second. For these rates it takes approximately 132 seconds, 17 seconds, or 2 seconds to transmit one frame.

One of the analog words has a 16-element subcommutator associated with it. This subcommutator has the capability of selecting in sequence any one of 16 slowly varying quantities. Thus, at the three transmission rates it will take approximately $\frac{1}{2}$, $4\frac{1}{2}$, or 35 minutes to complete an entire subcommutator cycle.

The method of transmitting the telemetry information to the ground is to biphase modulate a subcarrier which in turn phase modulates a radio-frequency carrier. This technique has the advantages of providing a continuous carrier for acquisition and tracking from the ground and an unambiguous resolution of the pulse data through the use of an adjacent pulse comparison biphase demodulator without a ground coherent oscillator. A disadvantage of this technique is an approximately 6-db loss in signal-to-noise ratio because of the limited subcarrier modulation power.

Areas of improvement are the use of biphase modulation of the carrier, the use of multiple bit encoding, and the sophistication of the logical design of the system.

In addition the Telebit system may be improved by expanding analysis or processing of the experimental data before transmission. For example, in the present Telebit system, the micrometeorite count is stored for a period of 6 to 10 hours and thus the resulting transmission from the satellite to the ground provides an average rate for a 6-hour period and then, as the experiment is read out again, the average rate for a $2\frac{1}{2}$-minute interval. A relatively simple change in the digital circuit logic would permit one to record during the 6-hour period the maximum counting rate that occurred in any one of the $2\frac{1}{2}$-minute intervals, the minimum counting rate that occurred in any of the $2\frac{1}{2}$-minute intervals, and the times at which these maximum and minimum rates occurred, in addition to the average count for the entire six-hour period. By the skillful application of such satellite data processing, considerable increases in the amount of information obtained from the experiments can be achieved without appreciably increasing the requirements on the total information channel capacity.

Finally, as data is accumulated, experimenters will be better able to define the steps required for the analysis of the data. At this point it will be possible to program the central computer to accomplish the mechanical part of the data analysis in addition to its normal task of data reduction. This ability to approach the ideal of real time analysis of experimental data is perhaps the most important single characteristic of the digital telemetry system.

THE PRESENT BOUNDARIES OF SPACE COMMUNICATION

The preceding paragraphs have developed the limitations and the characteristic parameters of the transmitter, the receiver, and the modulation subsystems, which together make up the building blocks of any space communication system. These results may be combined and summarized as in Fig. 11, where the information rates that can be achieved with present, or at least reasonably foreseeable, space communication systems are plotted against range to the vehicle. The curves assume that an optimum distribution of the weight between the satellite antenna and the satellite transmitter is achieved and that the best parametric amplifiers are used in the receiver. Several combinations of receiver-antenna area and transmission system weight are assumed which are characteristic of the several space missions.

From these curves it is evident that for low-altitude satellites, and reasonable payload weights, very large amounts of information can be transmitted. For instance, with ten pounds devoted to the transmitter and antenna system, it is possible to send a television picture from a satellite in a five-hundred mile orbit to a 60-foot antenna on the ground. Referring back to Fig. 1,

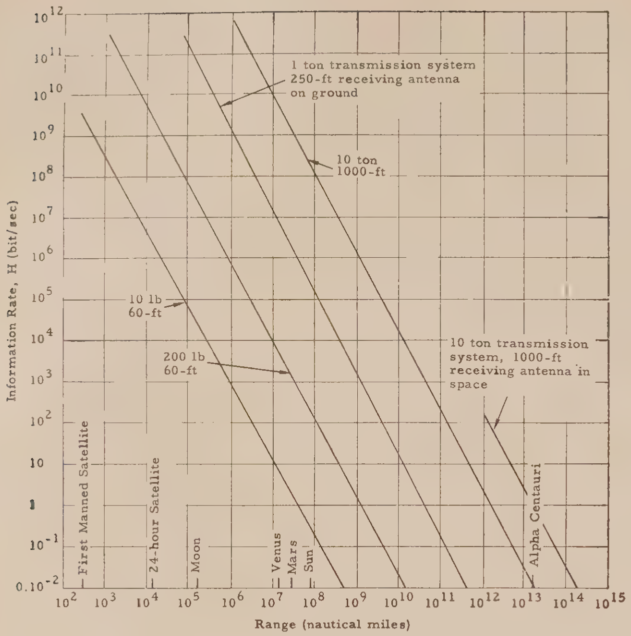

Fig. 11—Information rate, H, as a function of range for various combinations of payload antenna and transmitter weights and receiving antennas.

this corresponds to a transmitter power of only $\frac{1}{10}$ of a watt and an antenna gain of about 100.

As another example, in a 24-hour orbit it is possible, with 200 pounds of transmitter, power supply and antenna, to send 10^9 bits per second to a 60-foot antenna on the earth, which is the information contained in about 200 television channels.

Another class of space mission is that involving exploration of the moon. For this mission, the same 200-pound system is capable of transmitting a television picture, or 10^7 bits per second of information from the moon to the earth. If only ten pounds can be devoted to the transmitter-antenna combination, the maximum amount of information drops to 10^4 bits per second, and if a nondirectional antenna is necessary, the maximum information drops to 100 bits per second for a ten-pound weight.

The third class of space mission is the exploration of Venus or Mars, an era of space communication which is almost upon us. Here the ten-pound system, with an optimum antenna-transmitter, is capable of transmitting only one bit per second, although the 200-pound system will provide an information rate on the order of 1000–5000 bits per second at the minimum distance between earth and Mars or Venus. If transmission is desired from a satellite circling Mars or Venus, then the 200-pound transmitter will permit transmission of 100 bits per second over the entire path of Mars, providing a 250-foot diameter antenna is used on the earth. To transmit video from a satellite orbiting Venus or Mars will require transmission systems of between one and ten tons, and ground antennas between 250 and 1000 feet in diameter. As an example, 50 million bits per second can be transmitted from Mars in its extreme position using a ten-ton optimum payload with a 1000-foot receiving antenna on the ground.

Perhaps the most challenging space mission involves communication with an interstellar probe. Even with a ten-ton transmission system and a 1000-foot receiving antenna on the earth's surface, it is barely possible to track a probe to the nearest star, Alpha Centauri. The information rate at these distances is so low (only 1/100 bit per second), and the required oscillator stability so high (one part in 10^{12}), that such a mission is not, strictly speaking, within the present state of the art of our components. One alternative that provides reasonable, although still very small, information rates is to place the receiving antenna in a satellite orbit around the earth at an altitude such that the heat contribution of the earth's surface to the received energy in the antenna is small. If this can be done, the inherent low-noise properties of maser amplifiers may be fully realized. Then the ten-ton optimum system transmitting into a 1000-foot antenna at an altitude of about five thousand miles above the earth's surface would provide an information rate of about one bit per second from Alpha Centauri.

This last example is illustrative of the tremendous problems associated with direct communication over interstellar distances. If the problems of locating and stabilizing communication repeater stations could be solved, the proper placement of a hundred such vehicles would permit transmission of 100 bits per second to Alpha Centauri. Since the time of flight for these missions will be tens of years, a new order of component reliability is also required.

It is clear that both a considerable improvement in the entire transmission system and in our basic communication system concepts will be required before practical interstellar communication is feasible.

To summarize, the present practices in transmitter design, in solar cell power sources, in receiver design, and in antenna design, have been explored. The fundamental limitations on modulation efficiency have been examined, and two examples of modern practice have been described. Because of the limitations imposed by the conservation of energy, both in generating power and in the modulation of this power for the transmission of information, improvements in subsystems, although they will occur, are not likely to be order-of-magnitude improvements. Nevertheless, it appears that communication with large information rates is possible throughout the solar system.

ACKNOWLEDGMENT

The system studies considered here are in large part the result of creative effort of many of my colleagues. The paper itself is due in large measure to R. A. Park.

Propagation and Communications Problems in Space*

JOSEPH H. VOGELMAN†, FELLOW, IRE

Summary—**The problems of propagation and communications arising from landings on the Moon, Venus, or Mars are treated in terms of the characteristics required for the communication system to achieve data transfer between parties on the surface of these bodies and the communications problems arising in the transfer of information from these bodies back to the Earth. Consideration is given to Doppler shift, Faraday rotation, tracking and stabilization of antennas, and ground network requirements. The problems of communications between vehicles in space in terms of signal acquisition and antenna orientation and tracking are described.**

INTRODUCTION

THE recent literature has concerned itself with the problems of communications by means of vehicles in space serving as passive or active reflectors, and with problems of communications to vehicles traveling in space. This paper will treat the problems of propagation and communications arising from landings on the Moon, Venus, or Mars. Each of these will be treated in terms of the characteristics required for the communication system to achieve data transfer between parties on the surface of these bodies and the communications problems arising in the transfer of information from these bodies back to the Earth. The second case which will be considered is communications between vehicles in space.

GENERAL FACTORS

The frequency bands available for communications from the Earth to any other celestial body are limited by the radio frequency characteristics of the Earth's atmosphere. Accordingly, for communications to the Moon, Mars, or Venus, communications bands are available in Table I, where the frequency band from 100 to 10,000 mc appears to be the logical band of operation. Fig. 1 gives the transmission power in dbw/cps vs range for inverse square spreading assuming 0 db noise figure at the receiver. Fig. 2 gives the beamwidth in degrees at the half power points for parabolic antennas as a function of the antenna diameter. It also gives the effective gain achieved by these antennas. Fig. 3 shows the range which may be achieved at 50 mc. These curves use a receiver noise figure of 3 and a transmission antenna gain of 10^4. Values are given for combined transmitter and receiver antenna gains of 10^4 and 10^6 for receiver noise powers corresponding to values from 10^{-13} watts to 10^{-17} watts.

The obstacles to communications from the Earth to Mars, Venus, and the Moon are the following:

1) Doppler shift due to the relative motion of the body with respect to the Earth. These values are of the order of 0 to 106.4 cycles per megacycle of RF signal for transmissions from Earth to Mars and 0 to 112.7 cycles per megacycle for transmissions from Earth to Venus.

2) Doppler shifts due to the rotation of the Earth on its axis as well as the rotation of the other planets on their axes. The Doppler shift due to the rotation of the Earth for communication to the Moon varies from 0 to 0.199 cycle per megacycle of RF at the pole to 1.362 cycles per megacycle at New York City.

3) Faraday rotation due to the variable density of the Earth's atmosphere and its magnetic field. This rotation is maximum at the lowest frequency and a minimum at the highest. It is a maximum at the horizon and is essentially zero along a path perpendicular to the surface of the earth.

4) Tracking and stabilization of large antennas, possibly as large as 1000 feet on a side, are required to insure that the receiving station on the Moon, Mars, or Venus is within the main lobe of the antenna pattern.

5) Axial rotation of Venus and Mars will require a ground network on these planets to insure that the earth transmitters and receivers are in view.

6) In the case of the Moon one side is always in view of the Earth while the other is always invisible. This necessitates a communications system along the surface of the Moon or an appropriate lunar satellite in the event that communication with the far side is required.

The Doppler requirements discussed here would necessitate Doppler correction provisions or increased receiver bandwidths to insure that signals transmitted from the Earth would always be received in space. For an Earth to Mars link at 2000 megacycles this bandwidth would have to exceed 200 kilocycles even when the Doppler shift due to the rotation of Mars is neglected. This increase in diameter translates itself into the requirements for 13 db increase in transmitter power for a 10-kc information channel.

COMMUNICATIONS ON THE MOON

Line-of sight radio waves for transmissions along the surface of the Moon are of very short range due to the small radius of curvature of the Moon. Unless high mountain peaks can be used as relay points, this type of transmission does not appear desirable.

Low frequency ground waves of narrow bandwidth, however, appear entirely practical. The significantly lower gravitational field and the absence of wind and weather make extremely efficient large antennas practical at low frequencies.

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* Original manuscript received by the IRE, December 2, 1959.

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TABLE I

Frequency Band	Type	Characteristics
100 to 10,000 mc	Tropospheric	Scattered in troposphere Diffracted by obstacles Line of sight
10^4 to 7.5×10^8 mc	Millimeter and infrared	Line of sight Absorbed by atmosphere
7.5×10^8 to 1.5×10 mc	Light	Visible to human eye Scattered by atmosphere Absorbed by clouds

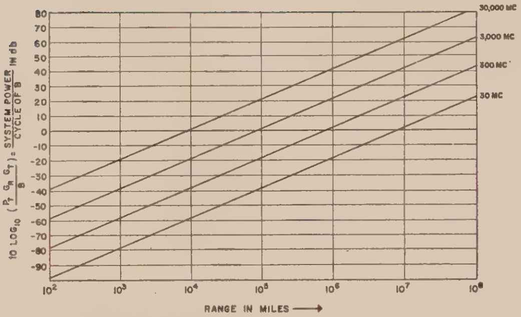


Fig. 1—System transmission power in dbw/cps vs range for inverse square spreading; 0-db noise figure.

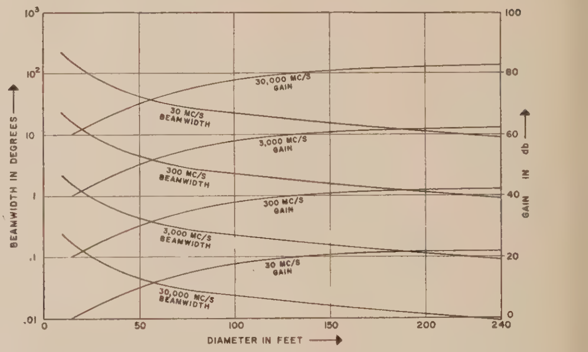
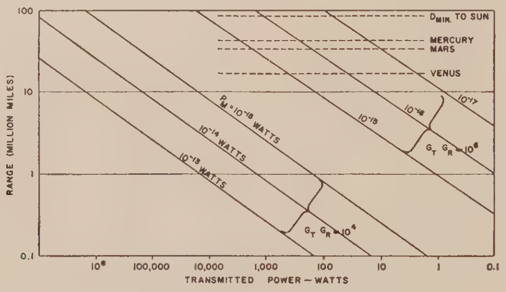


Fig. 2—Half-power beamwidth for parabolic antenna vs diameter



For other frequencies multiply transmitter power by

$$\left(\frac{fmc}{50}\right)^2$$

$$R = \frac{1.48\times10^2}{fmc}\sqrt{\frac{P_T G_T G_R}{P_M}}$$

$P_M = KTB\ N_f$ (losses) (integ. loss)
$K = 1.380\times10^{-23}$ joules/°K
T = temperature—°K
B = bandwidth—cps
N_f = noise figure

Fig. 3—Range of one-way radio at 50 mc.

Alternately, the lunar relay satellite of the active type may be used to provide the necessary path to a retransmitting station on the near side of the Moon.

Communications on Mars or Venus

A significant increase is required in information regarding the atmospheres of Mars and Venus, the nature of their magnetic fields and the extent of the ionized layers above their surfaces. Until such information becomes available, it must be assumed that surface communications will be limited to line-of-sight waves and the possible employment of a satellite orbiting these planets. The possibility of using ionospheric reflecting modes, tropospheric and ionospheric scatter as well as meteoric scatter cannot be determined at this time. Atmospheric conditions on these planets may impose frequency restrictions considerably different from those encountered on the Earth. It is to be hoped that the radio frequency windows on these planets are compatible with the radio frequency windows on Earth.

The major restriction on communications from the Earth to Mars and Venus is the presence of the sun along the radio path between the Earth and these planets for a portion of their orbits. The sun is a radio frequency source of tremendous power and is considerably closer to the Earth for a good portion of the planetary orbit. As a result, it will prevent communication for a considerable portion of the time. This radio silence can only be overcome by means of a solar satellite having an orbital path such that it permits both the Earth and the planet to view the repeater satellite without receiving the radio energy of the sun. The satellite will also require directive antennas to minimize solar radio noise in its receiver.

COMMUNICATIONS BETWEEN VEHICLES AND SPACE

The vacuum that is space imposes no frequency restrictions on the communications devices. Redirected modulated sunlight or solar radio energy can be used as well as radio waves. The major problem of vehicle to vehicle communication is the requirement that each vehicle should know where it is located with respect to the other. The acquisition problem is extremely difficult. The possibilities for acquisition are as follows:

1) A preplanned communications program for the two vehicles would require that the orbiting information of each vehicle be precisely known to the other and that computational equipment be included in the vehicle for the orientation of antennas.

2) Use of the Earth as a relay is another possibility. With the Earth maintaining continuous track of all vehicles in space, it would be possible for a vehicle to communicate to the Earth and have the message repeated and redirected to the second vehicle.

3) Alternately, the Earth may be used as an acquisition director furnishing continuously or "on request" position information for all vehicles in space.

Once acquisition has been achieved, tracking in space is possible by using a continuous reference transmission for receiver antenna lock-on and by synchronizing the transmitting antenna to the receiving antennas.

CONCLUSION

Table II summarizes the problems of communications in space between vehicles, and between the Earth, Mars, and Venus.

TABLE II

Location	Frequency Band	Obstacles
Earth to planet	100 to 10,000 mc	Doppler shift Faraday rotation Tracking and stabilization
Space to space	3 mc	Antenna size
	3 to 10,000 mc	Antenna size Power
	10^4 to 10^{10} mc	Tracking and stabilization
On the moon	3 mc (ground wave)	Antenna size Power
	3 to 10^{10} mc (line of sight)	Very short range
On the planets	3 mc (ground wave)	Antenna size
	3 to 30 mc (reflected wave)	Ionosphere ?
	30 to 10,000 mc	Scatter ? Meteors ? ?
	10,000 mc	?

Propagation-Doppler Effects in Space Communications*

F. J. TISCHER†, SENIOR MEMBER, IRE

Summary—**A generalized form of the Doppler equation is derived by field theory. The equation permits consideration of the effect of propagation phenomena on the Doppler shift under space flight conditions. As an example of an application, the effect of a medium which is nonhomogeneous in the flight direction is investigated. A deviation of the longitudinal and a transverse Doppler shift are the consequences. The magnitudes of both effects, which have to be taken into account in tracking, navigation, and Doppler evaluations, are considered.**

INTRODUCTION

DUE to the high velocities encountered in space flight, the Doppler phenomenon becomes very pronounced. It causes undesired frequency deviations which affect the operation of any kind of communications system, and which have to be taken into account, but it can also be utilized as a most useful tool in the physics and technology of space exploration, navigation, and tracking.

It can be anticipated that space flight conditions will affect the Doppler shift and that effects heretofore neglected will become apparent.[1] Wave propagation phenomena are among these effects. The anticipated influences were in fact observed and discussed in connection with Doppler measurements of radiations transmitted by satellites.[2] Other effects are due to relativity but, at the present state of the art of rocketry, these are not of significant magnitude.

It is the purpose of this study to investigate the effects of propagation phenomena on the Doppler shift. It may be noted for clarification that the effects considered as propagation phenomena are those which are not directly apparent from the commonly used equation for the Doppler shift, $\Delta\omega = \omega(v/c)\cos\alpha$, where ω is the operational frequency, v and c are the velocities of the vehicle and of the waves, respectively, and α is the angle between the direction of wave propagation and the flight path. These effects are primarily due to the nonhomogeneities of the medium (ionosphere, electron clouds) along the flight path of the vehicle or along the propagation path of the waves between the vehicle and the other station.

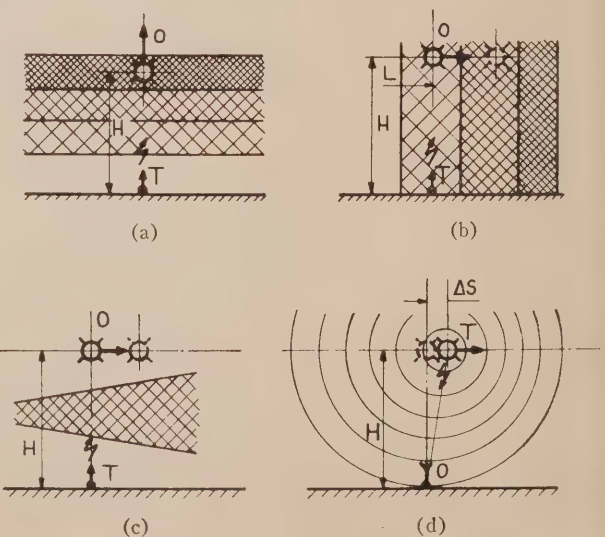
To study the effects of propagation phenomena on the Doppler shift, the above equation is not sufficient. A new formulation is necessary. Equations for the Doppler shift based on an optics method, which is an approximation, were derived previously.[1] The rigorous derivation must be based on field theory.

The first part of this study consists of a derivation of the Doppler shift by field theory, taking into account nonhomogeneities of the medium. The derived relations are used in the latter part to consider typical deviations from the regular Doppler shift due to the influence of the propagation phenomena.

Let us, as an introduction, consider some examples of propagation phenomena which affect the Doppler shift. Fig. 1 shows the operational conditions under which they occur. Fig. 1(a) indicates a vertical stratification of the medium, as it is typical for ionospheric layers. A transmitter T is placed on the ground, and the vehicle, in which an observer O is located, travels at a height H with a velocity v in the vertical direction. The question arises: How is the Doppler shift affected by the propagation phenomena?

The assumptions made for the second example are shown in Fig. 1(b). Such a stratification along the flight path occurs if the satellite travels in a region of varying electron density (border between day and night) in the horizontal direction. The resulting frequency deviation may be called a "transverse" Doppler shift. No Doppler shift would be observed without the influence of the medium.

A third kind of propagation effect is indicated in Fig. 1(c) with a layer of varying thickness, in which the propagation constant is different. An electron cloud of varying thickness may have a similar effect. Again, a transverse Doppler shift may be observed.



(a) (b)

(c) (d)

Fig. 1—Examples for the operational conditions for irregular Doppler shifts.

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* Original manuscript received by the IRE, December 2, 1959.

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[1] F. J. Tischer, "Doppler phenomena in space communications," IRE TRANS. ON COMMUNICATIONS SYSTEMS, vol. CS-7, pp. 25–30; May, 1959.

[2] P. R. Arendt, "Preliminary results of measurements on Doppler shift of satellite emissions," IRE TRANS. ON ANTENNAS AND PROPAGATION, vol. AP-7, pp. 99–101; January, 1959.

Concerning the transverse Doppler shift, it may be noted that the finite travel time of the waves from the transmitter to the observer also causes a form of transverse Doppler shift, for which Fig. 1(d) explains the operational conditions. If a transmitter T is placed in a vehicle, zero Doppler shift is observed, when the vehicle is located at a distance $\Delta S=(v/c)H$ from the zenith position at a time $\Delta T=H/c$ after passing the zenith.

DOPPLER SHIFT IN NONHOMOGENEOUS MEDIA

We have to use electromagnetic field theory in deriving rigorously the Doppler shift. The derivation is based on the following assumptions. A radiating system, given by a distribution of a current density $\bar{J}(\bar{r}')$, is located near the origin of a coordinate system. The consequence is an electromagnetic field which depends on the medium surrounding the radiator. In this field, an observer (receiver) is moving with a vector velocity $\bar{v}$. Its instantaneous position is given by $\bar{r}$. As shown previously, the observed angular frequency ω' is

$$\omega' = \omega + \frac{d\phi(\bar{r})}{dt} = \omega + \Delta\omega, \tag{1}$$

where ω is the frequency of the transmitter $[\exp(j\omega t)]$, ϕ is the phase angle of the observed field strength, and $\Delta\omega$ is the Doppler shift due to the motion of the receiver. We find

$$\Delta\omega = \frac{d\phi(\bar{r})}{d\bar{r}} \cdot \frac{d\bar{r}}{dt} = \nabla\phi\cdot\bar{v}. \tag{2}$$

This result is in agreement with that of rigorous treatments where the observer is placed in a second coordinate system moving with the vector velocity $\bar{v}$. The Doppler frequency obtained by the use of the Lorentz transformation (frequency in the moving frame) is

$$\omega' = (\omega - \nabla\phi\cdot\bar{v})/[1-(v/c)^2]^{1/2}.$$

The denominator in this equation takes into account a deviation due to relativity which is neglected above.

As a first step, we derive the observed field strength $\bar{E}(\bar{r})$, the phase of which gives the Doppler shift according to (2).

It may be noted that the results based on these assumptions also are applicable to the case of a mutually interchanged transmitter and receiver for nonrelativistic speeds and isotropic media due to the reciprocity theorem.

The properties of the medium are defined by a relative permittivity $\epsilon_r(\bar{r}')$ which may be complex, where

$$\epsilon_r(\bar{r}') = 1 + \Delta\epsilon_r(\bar{r}'). \tag{3}$$

Let us start with an evaluation of Maxwell's equations for the complex amplitude of the field magnitudes E, D, H, and B according to the following equations using customary procedures:

$$\nabla \times \bar{E} = -j\omega\mu_0\bar{H}, \tag{4}$$

$$\nabla \times \bar{H} = j\omega\epsilon_0\epsilon_r(\bar{r}')\bar{E} + \bar{J}, \tag{5}$$

$$\nabla\cdot\bar{B} = 0, \qquad \nabla\cdot\bar{H} = 0, \qquad \bar{B} = \mu_0\bar{H}, \tag{6}$$

$$\nabla\cdot\bar{D} = 0, \qquad \nabla\cdot[\epsilon_0\epsilon_r(\bar{r}')\bar{E}] = 0, \tag{7}$$

$$\epsilon_0\epsilon_r(\bar{r}')\nabla\cdot\bar{E} + [\nabla\epsilon_0\epsilon_r(\bar{r}')]\cdot\bar{E} = 0, \tag{8}$$

$$\nabla\times\nabla\times\bar{E} = -j\omega\mu_0\nabla\times\bar{H} = \omega^2\epsilon_0\mu_0\epsilon_r(\bar{r}')\bar{E} - j\omega\mu_0\bar{J}; \tag{9}$$

$$\nabla\times\nabla\times\bar{H} = j\omega\epsilon_0\epsilon_r(\bar{r}')\nabla\times\bar{E} + j\omega\epsilon_0[\nabla\epsilon_r(\bar{r}')\times\bar{E}] + \nabla\times\bar{J}. \tag{10}$$

Introducing the identity

$$\nabla\times\nabla\times\bar{E} = \nabla(\nabla\cdot\bar{E}) - \nabla^2\bar{E}, \tag{11}$$

we obtain

$$\nabla\times\nabla\times\bar{E} = -\nabla\left(\frac{\nabla\epsilon_r(\bar{r}')\cdot\bar{E}}{\epsilon_r(\bar{r}')}\right) - \nabla^2\bar{E}, \tag{12}$$

$$\nabla\times\nabla\times\bar{H} = -\nabla^2\bar{H}, \tag{13}$$

and finally

$$\nabla^2\bar{E} + \beta_0{}^2\bar{E} = j\omega\mu_0\bar{J} - \nabla\left(\frac{\nabla\epsilon_r(\bar{r}')\cdot\bar{E}}{\epsilon_r(\bar{r}')}\right) - \beta_0{}^2\Delta\epsilon_r(\bar{r}')\bar{E}, \tag{14}$$

$$\nabla^2\bar{H} + \beta_0{}^2\bar{H} = -j\omega\epsilon_0[\nabla\epsilon_r(\bar{r}')\times\bar{E}] - \beta_0{}^2\Delta\epsilon_r(\bar{r}')\bar{H}' - \nabla\times\bar{J}, \tag{15}$$

where $\beta_0{}^2=\omega^2\epsilon_0\mu_0$, with ϵ_0 and μ_0 for the permittivity and permeability of free space.

The wave equations (14) and (15) for the field distributions can be solved by diadic Green's functions. We solve for $\bar{E}$ at the position $\bar{r}$ of an observer and obtain an integral equation

$$\bar{E}(\bar{r}) = \int_V \bar{\Gamma}(\bar{r},\bar{r}')\cdot\left\{\bar{J} + j\frac{\omega\epsilon_0}{\beta_0{}^2}\nabla\left[\frac{\nabla\epsilon_r(\bar{r}')\cdot\bar{E}}{\epsilon_r(\bar{r}')}\right] + j\omega\epsilon_0[\Delta\epsilon_r(\bar{r}')\bar{E}]\right\} dV, \tag{16}$$

where

$$\bar{\Gamma}(\bar{r},\bar{r}') = \frac{1}{4\pi j\omega\epsilon_0}(\beta_0{}^2\mathrm{E} + \nabla\nabla)\frac{\exp(-j\beta_0|\bar{r}-\bar{r}'|)}{|\bar{r}-\bar{r}'|)} \tag{17}$$

is the diadic Green's function for the three-dimensional space.[3]

The final solution for $\bar{E}$ can be written as a series

$$\bar{E}(\bar{r}) = \bar{E}_0(\bar{r}) + \sum_{n-1}^{\infty}\Delta\bar{E}_n(\bar{r}). \tag{18}$$

The first term $[\bar{E}_0(\bar{r})]$ is the field distribution for empty space. It is

$$\bar{E}_0(\bar{r}) = \int_V \bar{\Gamma}(\bar{r},\bar{r}')\cdot\bar{J}(\bar{r}')dV. \tag{19}$$

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[3] H. Levin and J. Schwinger, "On the theory of electromagnetic wave diffraction by an aperture in an infinite plane conducting screen," in "Theory of Electromagnetic Waves, a Symposium," Interscience Publishers, Inc., New York, N. Y., pp. 1–37; 1951.

Introduction of (18) in (16) yields a recursion formula for the sum terms

$$\Delta\overline{E}_n(\bar{r}) = \int_V \overline{\Gamma}(\bar{r}, \bar{r}') \cdot \left\{ j \frac{\omega\epsilon_0}{\beta_0{}^2} \nabla \left[\frac{\nabla\epsilon_r(\bar{r}') \cdot E_{n-1}}{\epsilon_r(\bar{r}')} \right] + j\omega\epsilon_0 [\Delta\epsilon_r(\bar{r}')\Delta\overline{E}_{n-1}] \right\} dV \qquad (20)$$

where, for $n=1$, $\Delta\overline{E}_{n-1}=\overline{E}_0$.

Thus, the solution consists of a contribution by the incident waves $\overline{E}_0$ which would be obtained as a solution for $\Delta\epsilon_r=0$ and the sum of contributions due to waves scattered by the medium.

If $\Delta\epsilon_r \ll 1$, we can neglect terms of higher order and obtain

$$\overline{E}(\bar{r}) \approx \overline{E}_0 + \Delta\overline{E}_1. \qquad (21)$$

Knowing $\overline{E}(\bar{r})$, we must proceed to evaluate it from the viewpoint of the application in (2). Let us write

$$\overline{E}(\bar{r}, t) = \overline{E}(\bar{r}) \exp(j\omega t) = \overline{A}(\bar{r}) \exp[j\phi(\bar{r})] \exp(j\omega t). \qquad (22)$$

A known identity yields

$$\log_n A(\bar{r}) = \mathrm{Re}\left[\int_0^s \frac{dE(\bar{r})}{ds'} \Big/ E(\bar{r}) ds' \right] \qquad (23)$$

and

$$\phi(\bar{r}) = \mathrm{Im}\left[\int_0^s \frac{dE(\bar{r})}{ds'} \Big/ E(\bar{r}) ds' \right]. \qquad (24)$$

Introduction of (24) in (2) gives

$$\Delta\omega = \nabla\left\{ \int_0^s \mathrm{Im}\left[\frac{dE(\bar{r})}{ds'} \Big/ E(\bar{r}) \right] ds' \right\} \cdot \bar{v}. \qquad (25)$$

We give s the direction of $\bar{v}$ and obtain

$$\Delta\omega \approx \mathrm{Im}\left[\frac{dE(\bar{r})}{d(\bar{v}t)} \Big/ E(\bar{r}) \right] v. \qquad (26)$$

Finally, if $\Delta\epsilon_r \ll 1$, it is as an approximation

$$\Delta\omega \approx \mathrm{Im}\left[\frac{d(E_0 + \Delta E_1)}{d(\bar{v}t)} \Big/ E_0 \right] v. \qquad (27)$$

The derivation is interesting, in so far as it shows that field theory permits straightforward calculation of the Doppler shift under complicated conditions of wave propagation. From this viewpoint, the above procedures may also be valuable as tools for the calculation of other problems.

Let us now use the derived equations (18), (20), and (27) to calculate some typical cases of the effect of the wave propagation on the Doppler shift.

EXAMPLE I—DEVIATION OF THE LONGITUDINAL DOPPLER SHIFT IN A VERTICALLY STRATIFIED MEDIUM

We consider as a first example the deviation of the longitudinal Doppler shift in a vertically stratified medium as it is indicated in Fig. 1(a) and described in the Introduction. Such deviations may occur and introduce errors when the Doppler shift is utilized for navigation in launching a space vehicle or in a terminal guidance system. If a profile of the properties of the medium is known, one can take these deviations into account and reduce the errors.

The following simplifying assumptions are made. We place a rectangular coordinate system with the X and Y axes on the ground as indicated in Fig. 2. Plane waves

$$E_x = \exp[j(\omega t - \beta_0 z)], \qquad (28)$$

$$H_y = \frac{1}{Z_0} \exp[j(\omega t - \beta_0 z)], \qquad (29)$$

$$\beta_0 = \omega\sqrt{\epsilon_0\mu_0}, \qquad Z_0 = \sqrt{\mu_0/\epsilon_0} \qquad (30)$$

propagate in the positive Z direction. The medium is vertically stratified and defined by an eventually complex $\Delta\epsilon_r = f(z)$. The electric field strength is observed in the vehicle which travels with a velocity v_z in the vertical direction.

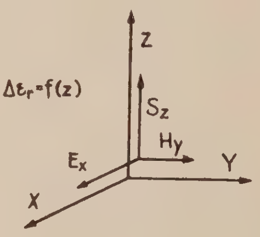

Fig. 2—Assumptions for Example I.

Under these conditions the incident field strength for $\Delta\epsilon_r=0$ is

$$\overline{E}_0(z, t) = \bar{\imath}_x \exp[j(\omega t - \beta_0 z)]. \qquad (31)$$

The properties of the medium are characterized by

$$\Delta\epsilon_r = f(z), \qquad \Delta\epsilon_r \ll 1, \qquad \nabla\epsilon_r = \bar{\imath}_z \frac{d\Delta\epsilon_r}{dz} \cdot \qquad (32)$$

For ionized gas (ionosphere), we find[4]

$$\Delta\epsilon_r = -(\omega_c/\omega)^2 \qquad (33)$$

where

$$\omega_c = 56\sqrt{N} \qquad (34)$$

[4] F. J. Tischer, "Wave Propagation Through Ionized Gas in Space Communications," Institute of the Aeronautical Sciences, New York, N. Y., IAS Rept. No. 59–34; January, 1959.

is the critical (plasma) frequency which depends, according to (34), on the electron density N (electrons per meter^3).

Considering the contributions to the field strength due to the medium (20), we find that the first term vanishes since $\nabla\epsilon_r$ and $\bar{E}$ are perpendicular to each other. We obtain

$$\Delta\bar{E}_1 = +j\omega\epsilon_0 \int_V \bar{\Gamma}(\bar{r}, \bar{r}')\cdot[\Delta\epsilon_r(z')\bar{E}_0]dV, \tag{35}$$

$$\Delta\bar{E}_1 = \frac{1}{4\pi}(\beta_0^2\mathrm{E} + \nabla\nabla)\int_v \bar{i}_z\Delta\epsilon_r(z') \cdot\exp\left[-j\beta_0(z' + R)\right]\frac{1}{R}\,rdrdz', \tag{36}$$

where $r=(x^2+y^2)^{1/2}$, $R=[(z-z')^2+r^2]^{1/2}$, and $rdr=RdR$. Integration in the horizontal plane yields

$$\Delta\bar{E}_1 = \bar{i}_x\left[-\frac{1}{2}\beta_0\exp(-j\beta_0 z)\int_0^z \Delta\epsilon_r(z')dz'\right]. \tag{37}$$

We introduce (37) in (27) and obtain finally for the Doppler frequency

$$\Delta f \approx -\frac{\beta_0}{2\pi}\left[1 + \tfrac{1}{2}\Delta\epsilon_r(z)\right]v_z = -\left[1 + \tfrac{1}{2}\Delta\epsilon_r(z)\right]\frac{v_z}{\lambda_0}, \tag{38}$$

where λ_0 is the free-space wavelength.

The relative deviation from the regular, free-space Doppler shift is then

$$S(z) = \tfrac{1}{2}\Delta\epsilon_r(z) = -\tfrac{1}{2}[\omega_c(z)/\omega]^2. \tag{39}$$

Fig. 3 shows a diagram of the deviation vs frequency with the electron density N as parameter.

It may be noted that this result could also have been obtained directly from the known Doppler equation. It may serve to check the correctness of the derived equations.

EXAMPLE II—TRANSVERSE DOPPLER SHIFT IN A NONHOMOGENEOUS MEDIUM

Let us consider as a further example the transverse Doppler shift under the conditions shown in Fig. 1(b), where the direction of wave propagation is perpendicular to the direction of the velocity vector. This case is interesting since no Doppler shift would occur in free space. Such a Doppler shift must be taken into account in evaluating Doppler measurements on satellites for the determination of electron densities and in Doppler navigation.

As before, we assume plane waves according to (28)–(30) traveling from the ground plane (X, Y plane) in the positive Z direction. The medium is stratified in the Y direction and the velocity vector $\bar{v}$ of the observer has a Y component only:

$$\Delta\epsilon_r = f(y'), \qquad \bar{v} = \bar{i}_y v_y. \tag{40}$$

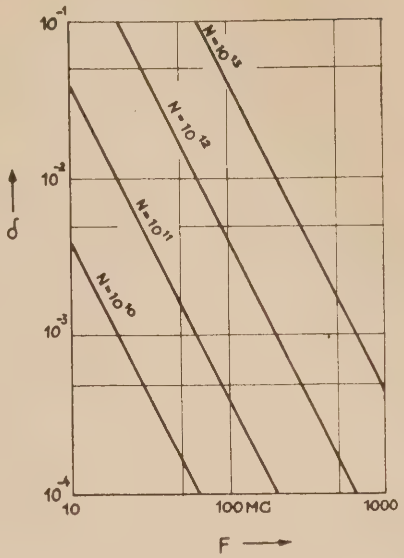

Fig. 3—Deviation of the Doppler shift in ionized gas vs frequency (N=electron density in particles per meter^3).

The incident field strength (for $\Delta\epsilon_r=0$) is

$$\bar{E}_0(z) = \bar{i}_x\exp(-j\beta_0 z). \tag{41}$$

Considering the contribution to the electric field strength due to the medium (20), we find that the first term vanishes. We obtain

$$\Delta\bar{E}_1(z) = j\omega_0\epsilon_0\int_V \bar{\Gamma}(\bar{r}, \bar{r}')\cdot[\Delta\epsilon_r(y')\bar{E}_0(z)]dV, \tag{42}$$

$$\bar{E}(z) = \bar{E}_0(z) + \frac{1}{4\pi}(\beta_0^2\mathrm{E} + \nabla\nabla) \cdot\int_V \Delta\epsilon_r(y')\bar{E}\,\frac{\exp\left[-j\beta_0|\bar{r}-\bar{r}'|\right]}{|\bar{r}-\bar{r}'|}dV. \tag{43}$$

Differentiation of (42)with respect to z yields

$$\frac{d\Delta\bar{E}(z)}{dz} = \frac{1}{4\pi}(\beta_0^2\epsilon + \nabla\nabla)\iint\frac{\Delta\epsilon_r(y)\bar{E}_0(z)\exp(-j\beta_0|R|)}{R}dxdy. \tag{44}$$

We assume that the variation of $\Delta\epsilon_r$ in the Y direction is small and expresses $\Delta\epsilon_r$ in the neighborhood of y_0 by

$$\Delta\epsilon_r(y) \approx \Delta\epsilon_r(y_0) + \frac{d\Delta\epsilon_r(y_0)}{dy}\Delta y, \tag{45}$$

where $\Delta y = R\sin\phi$, $R=(x^2+y^2)^{1/2}$, and $dxdy=rd\phi dr$. The variation of $\bar{E}$ in the Y direction is assumed to be negligible in the region where $\Delta\epsilon_r$ contributes to the field strength. Integrating (44), we obtain

$$\frac{d\Delta\bar{E}}{dz} \approx -j\frac{1}{2}\beta_0\Delta\epsilon_r(y_0)\bar{E}_0; \tag{46}$$

introducing

$$\frac{d\bar{E}_0}{dz} = -j\beta_0\bar{E}_0$$

yields the approximation

$$\frac{d\bar{E}}{dz} = -j\beta_0\left[1 + \frac{1}{2}\Delta\epsilon_r(y_0)\right]\bar{E}, \tag{47}$$

and finally

$$\bar{E}(y_0) \approx \bar{E}_0(0)\exp\left\{-j\beta_0\left[1 + \frac{1}{2}\Delta\epsilon_r(y_0)\right]z\right\}. \tag{48}$$

The Doppler shift is

$$\Delta\omega \approx -\frac{1}{2}\beta_0\frac{d[\Delta\epsilon_r(y)]}{dy}zv_y. \tag{49}$$

If $d[\Delta\epsilon_r(y)]/dy$ also varies in the Z direction, we can write as an approximation

$$\Delta\omega \approx -\frac{1}{2}\beta_0 v_y\int_0^z\frac{d[\Delta\epsilon_r(y)z]}{dy}dz. \tag{50}$$

For obtaining an idea about the magnitude of this transverse Doppler shift, let us consider a practical example after transforming (49) into

$$\Delta F = -\frac{1}{2}\frac{H}{\lambda_0}\frac{F_{c1}^2 - F_{c2}^2}{F^2}\frac{v}{\Delta L}, \tag{51}$$

where H is the height of a satellite ($H = 500$ km), F is the operational frequency ($F = 20$ mc, $\lambda_0 = 15$ meters), F_{c1} and F_{c2} are the cutoff frequencies at two locations $\Delta L (= 1000$ km) apart. F_{c1} and F_{c2} may have the values 4 and 6 mc. For the velocity, $v = 8$ km/second is chosen. We obtain

$$|\Delta F| = 7 \text{ cps.}$$

It can be seen that the effect decreases linearly with increasing frequency. Phase and frequency modulation can be expected due to this transverse Doppler shift.

The transverse Doppler shift is related to distortions of the phase front which may become serious in tracking satellites.

CONCLUSION

By formulating the Doppler effect mathematically in a general manner, one can derive relations for the Doppler shift under space flight conditions taking into account propagation effects which result mainly from nonhomogeneities of the medium along the flight path and along the path of the wave propagation. Ionospheric and interplanetary electron distributions can be considered as such nonhomogeneous media.

Field theory and the general formulation of the Doppler effect permit calculation of the deviations from the regular Doppler shift due to these propagation effects.

Of particular interest is a transverse Doppler shift which occurs when the flight path is perpendicular to the direction of wave propagation. No Doppler shift would be observed under normal conditions. Nonhomogeneous propagation causes such an irregular Doppler shift. It may be noted that a similar shift occurs due to relativity.

In space navigation, tracking, and exploration these and other effects must be taken into account. Theoretical calculations of the type shown can replace experimental investigations which, in space science, are extremely costly.

Communication Efficiency Comparison of Several Communication Systems*

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Summary—**Of increasing importance in communication systems, particularly those required for data transmission from space craft, is the minimization of the total transmitted energy required to transmit a given amount of data. Modulation systems can be compared on the basis of a figure of merit defined as the ratio of energy required per bit transmitted in the presence of a given noise spectral density. Using this criterion, several families of communication systems are compared in this article, including AM, FM, FM/FM, and orthogonal matched filter communication systems. It is found that the orthogonal systems uniformly require less power to transmit at a given information rate than other systems and approach closely the theoretical limit established by Shannon's channel capacity theorem.**

INTRODUCTION

A CONVENIENT way of comparing communications systems is to compare their efficiency in terms of β, the received signal energy required per information bit transmitted in the presence of a given uniform Gaussian noise spectral density.

$$\beta = \frac{E_{\min}}{\epsilon^2} \tag{1}$$

where

$E_{\min}$ = minimum received energy required per bit,
ϵ^2 = noise spectral power density (positive frequency).

Equivalently, β may be expressed as

$$\beta = \frac{P_{\min}}{\epsilon^2 H} \tag{2}$$

where

$P_{\min}$ = minimum received power required,
H = information rate (bits per second).

A lower bound on β may be derived from Shannon's channel capacity theorem

$$H = B \log_2\left(\frac{P_{\min}}{\epsilon^2 B} + 1\right)$$

$$\frac{H}{B} = \log_2\left(\beta_0 \frac{H}{B} + 1\right)$$

$$\beta_0 = \alpha(2^{1/\alpha} - 1) \tag{3}$$

where

B = channel bandwidth,
β_0 = channel limit of β for arbitrarily small probability of error,
$\alpha = B/H$.

From (3) it follows that a lower bound on β_0 is $\log_e 2 = 0.693$ which is attained as $\alpha \rightarrow \infty$, *i.e.*, for systems of unlimited bandwidth (and proper data encoding).

Eq. (2) may be rewritten in a form which facilitates β computations for various systems.

$$\beta = \frac{P_{\min}}{\epsilon^2 H} = \frac{P_{\min}}{\epsilon^2 B}\,\frac{B}{H} = \frac{S_i}{N_i}\,\alpha \tag{4}$$

where

S_i = input signal power,
N_i = input noise power.

Thus, for any given system, β may be computed from the input signal-to-noise ratio (for a desired error rate) and the ratio of bandwidth to information rate.

PULSE CODE MODULATION

As a detailed example of the method of computation of β efficiency, consider a PCM system where successive 0's and 1's are transmitted by means of phase modulation (that is, with equal power required for 0's and 1's). A maximum likelihood detector, where 0's and 1's are transmitted with equal probability, is one which divides the possible received signals into two sets such that the probability of recognizing the transmitted signal is maximized. For a detector whose output is $+A$ when a "0" is sent under noise-free conditions, $-A$ for "1", and is an odd function of signal plus noise between these limits, the maximum likelihood threshold is 0. Assuming band-limited Gaussian noise to be present in the output, the probability of error P_e is a symmetrical function of the transmitted signal, *i.e.*,

$$P(0 \mid 1) = P(1 \mid 0) = P_e = \Phi(-z) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{-z} e^{-x^2/2} dx$$

where

$P(0 \mid 1)$ = probability that a 0 is received when a 1 is transmitted,
P_e = probability of error per bit,
z = output signal-to-noise voltage ratio (rms).

The receiver input signal-to-noise power ratio required to produce an output signal-to-noise power ratio of z^2

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* Original manuscript received by the IRE, December 2, 1959.

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depends on the exact modulation and detection system employed. For any modulation technique, a suppressed carrier coherent detection system requires the least input power. For such a system where the input RF signal spectrum has twice the bandwidth of the modulating signal, the required input signal-to-noise ratio is $z^2/2$, since coherent detection causes the information sidebands to add coherently.

From the sampling theorem, the information rate is, under the preceding assumptions,

$$H = 2(B/2) = B,$$

since the modulation bandwidth equals half the information bandwidth assuming that the error probability is small. Therefore,

$$\alpha = \frac{B}{H} = 1$$

$$\beta = \frac{S_i}{N_i} \alpha = \frac{z^2}{2} \cdot \tag{5}$$

For example, if $P_e = 10^{-6}$, $z = 4.753$, $\beta = 11.30$. It should be noted that this resulting β is independent of the transmission bandwidth as long as suppressed carrier coherent detection systems are assumed. For example, if single sideband modulation is employed, α decreases to $\frac{1}{2}$, but the input signal-to-noise ratio required increases proportionately so that β remains the same.

However, β is significantly larger for noncoherent systems. For example, consider a noncoherent, PCM-AM system. Assuming that a low-pass filter restricts the modulating waveform to a bandwidth of $B/2$ and that each individual bit forms a $\sin x/x$ waveform, the input signal-to-noise power ratio S_i/N_i is

$$\frac{S_i}{N_i} = c \frac{S_s}{N_i},$$

where S_s is the peak input power of a single $\sin x/x$ pulse and c is the per unit number of ON pulses sent. Assuming that ON and OFF pulses (0's and 1's) are equally likely to be transmitted,

$$\frac{S_i}{N_i} = \frac{1}{2} \frac{S_s}{N_i} \cdot$$

A maximum likelihood envelope detector is one where the decision threshold between 0's and 1's is such that $P(0|1) = P(1|0)$, as before. For a given bit error probability P_e, this occurs where

$$P_e = \int_z^\infty x e^{-x^2/2} dx = \int_0^y x e^{-(x^2+a^2)/2} I_0(ax) dx, \tag{6}$$

where

y = decision threshold,

$$a = \sqrt{\frac{2S_s}{N}} \cdot$$

The integrand of the first integral of (6) is the probability density function of the envelope of narrow-band Gaussian noise. The integrand of the second integral is the probability density function of the envelope of a sine wave plus narrow-band Gaussian noise, where $I_0(ax)$ is the modified Bessel function.

For $P_e = 10^{-6}$, (6) gives $y = 5.257$, $a = 7.068$. For $c = 0.5$,

$$\frac{S_i}{N_i} = ca^2 = \frac{1}{2}(7.068)^2 = 24.98.$$

The input bandwidth is twice the data bandwidth B_d. Therefore,

$$\alpha = \frac{2B_d}{2B_d} = 1,$$

$$\beta = \frac{S_i}{N_i} \alpha = 24.98.$$

Thus, noncoherent, noncarrier-suppressed PCM requires slightly more than 3 db transmitted power to communicate at a given information rate than does a coherent PCM system assuming all other system parameters are held constant. This result assumes that the threshold is ideally established. In practical PCM systems, β often exceeds 100.

AMPLITUDE MODULATION

For a suppressed carrier, coherent detection double sideband amplitude modulation system, the output signal-to-noise ratio in a square bandwidth B_d is equal to twice the input signal-to-noise ratio (in a bandwidth $2B_d$). In other words,

$$\frac{S_i}{N_i} = \frac{1}{2} \frac{S_0}{N_0} \cdot \tag{7}$$

The ratio of RF bandwidth B to information rate H is

$$\alpha = \frac{B}{H} = \frac{2B_d}{2B_d H'} = \frac{1}{H'}, \tag{8}$$

where H' is the number of bits transmitted per single sample.

From (4) and (7) it follows that β is

$$\beta = \frac{1}{2H'}\left(\frac{S_0}{N_0}\right) \cdot \tag{9}$$

To compute β where suppressed carrier, coherent detection amplitude modulation is used to transmit analog data, use can be made of Table I where H' can be found by interpolation of the entries for various signal-to-noise ratios, assuming that the signal is uniformly distributed through the modulating interval. Alternatively, use can be made of (84) in Appendix I.

For the transmission of digital data, using amplitude modulation, it is necessary to quantize the modulating waveform into a number of levels. From (89) in Appendix I, β may be written as

$$\beta = \frac{L^2 - 1}{6H'} z^2 \tag{10}$$

TABLE I

EQUIVALENT SIGNAL-TO-NOISE RATIO ($10 \log_{10} S/N$) FROM (84) FOR INFORMATION RATE H' DEFINED FROM TABLE III FOR A CONTINUOUS CHANNEL WHERE THE TRANSMITTED SIGNAL IS UNIFORMLY DISTRIBUTED OVER AN INTERVAL AND THE NOISE IN THE CHANNEL IS NORMALLY DISTRIBUTED. P_e' IS THE ERROR RATE PER SAMPLE IF THE CHANNEL WERE USED TO TRANSMIT L-LEVEL DIGITAL DATA (88)

L	P_e'	$10 \log_{10} S/N$	H' Bits per Sample
4	0.0830	11.05	1.791
8	0.0558	18.58	2.921
16	0.0452	25.21	3.973
32	0.0414	31.46	4.992
64	0.0399	37.58	5.998
128	0.0393	43.64	6.999
256	0.0390	49.68	8.000
512	0.0389	55.71	9.000
1024	0.0388	61.74	10.000

TABLE II

PROBABILITY OF ERROR PER SAMPLE P_e', (90), AND REQUIRED SIGNAL-TO-NOISE RATIO ($10 \log_{10} S/N$), (89), FOR A CONTINUOUS CHANNEL TO TRANSMIT DIGITAL DATA AT A BIT ERROR RATE OF 10^{-6} ASSUMING A UNIFORM DISTRIBUTION OF SIGNAL LEVELS AND THE LINEAR ADDITION OF NORMALLY DISTRIBUTED NOISE IN THE CHANNEL

L	P_e'	$10 \log_{10} S/N$	H' Bits per Sample
2	10^{-6}	13.54	1.000
4	2×10^{-6}	20.42	2.000
8	3×10^{-6}	26.56	3.000
16	4×10^{-6}	32.55	4.000
32	5×10^{-6}	38.50	5.000
64	6×10^{-6}	44.46	6.000
128	7×10^{-6}	50.42	7.000
256	8×10^{-6}	56.39	8.000
512	9×10^{-6}	62.36	9.000
1024	10×10^{-6}	68.34	10.000

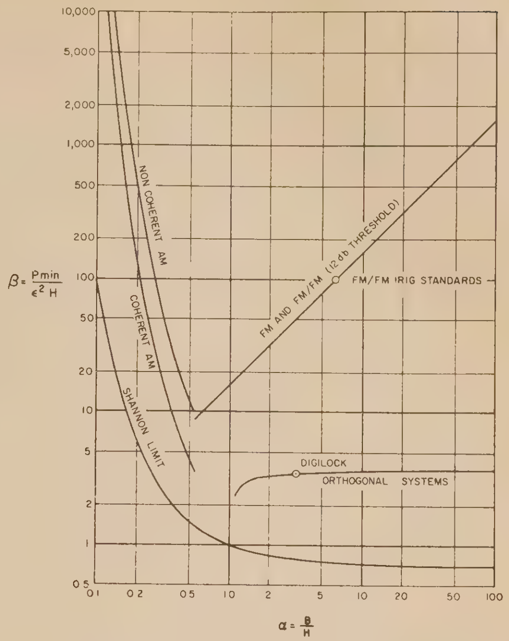

Fig. 1—B efficiency of various systems as a function of $\alpha = B/H$ for digital equivalent systems where rms quantizing noise equals rms error due to error rate ($\sigma_q = \sigma_e$).

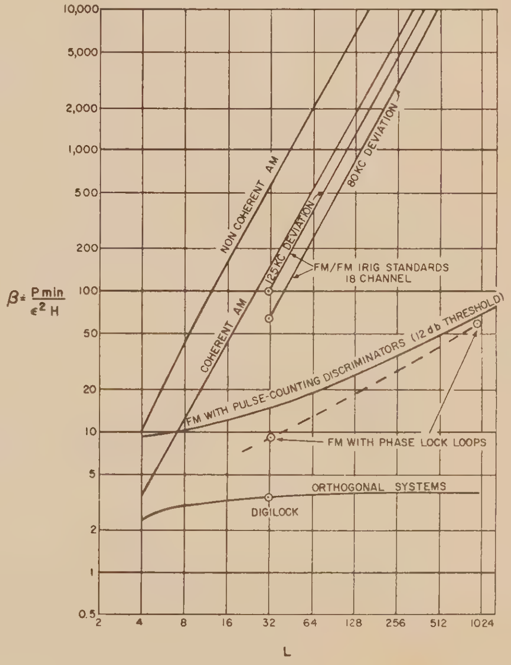

Fig. 2—B efficiency of various systems as a function of number of quantization levels L for digital equivalent systems where rms quantizing noise equals rms error due to error rate ($\sigma_q = \sigma_e$).

where, from (88)

$$P_e' = \frac{2(L-1)}{L}\Phi(-z). \tag{11}$$

In (10) and (11), L is the number of quantization levels and H' is defined by (85). The quantity z is defined by (11) for per sample error rate P_e'. $\Phi(-z)$ is the normal probability distribution function; *i.e.*,

$$\Phi(-z) = \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{-z} e^{-x^2/2}dx. \tag{12}$$

For a bit error rate of 10^{-6} the signal-to-noise ratios shown in Table II may be used in conjunction with (9) to obtain β. For other error rates use may be made of (10)-(12).

Results of computations for amplitude modulation of both analog and digital data sources are shown in Figs. 1–4. Figs. 1 and 2 show systems transmitting analog data. Fig. 1 shows β as a function of α, while Fig. 2 shows β as a function of L, the number of levels which would be required to transmit the analog information with a digital system under the conditions for digital systems assumed in deriving Table III. Figs. 3 and 4 show systems as a function of α and the number of levels L if they are used for the transmission of digital data.

For noncoherent double-sideband amplitude modulation systems, the values of β are consistently higher than those for the coherent case for any given α. An approximate analysis of the noncoherent case assumes that a linear detector is used to determine the envelope of the incoming waveform. It is further assumed that

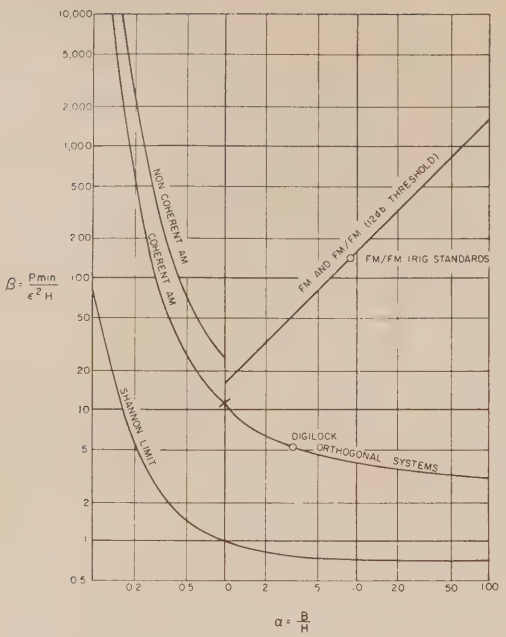

Fig. 3—*B* efficiency of various systems as a function of $\alpha = B/H$ for digital equivalent systems where the bit error rate $P_e = 10^{-6}$.

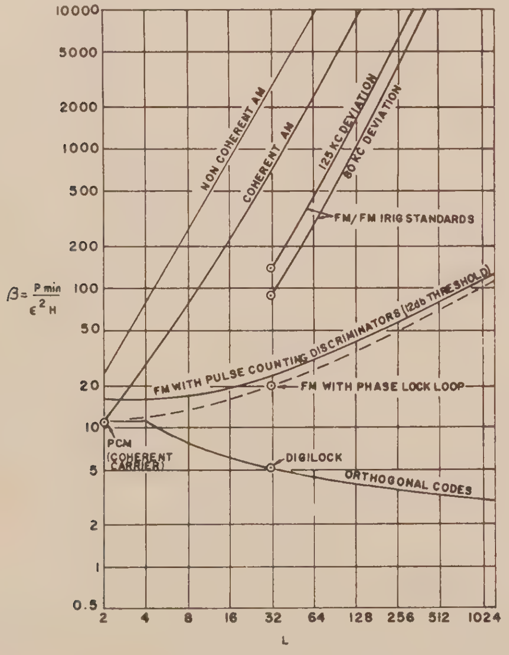

Fig. 4—*B* efficiency of various systems as a function of number of quantization levels *L* for digital equivalent systems where the bit error rate $P_e = 10^{-6}$.

TABLE III

EQUIVALENT SIGNAL-TO-NOISE RATIO (10 $\log_{10} S/N$) AND INFORMATION RATE H' (87) FOR QUANTIZED EQUAL-INCREMENT CHANNEL OF L-LEVELS WHERE RMS QUANTIZATION NOISE AND RMS ERROR DUE TO UNIFORM ERROR PROBABILITY P_e' ARE EQUAL

L	P'	10 $\log_{10} S/N$	H' Bits per Sample
4	0.025	8.75 decibels	1.791
8	0.00694	14.98 decibels	2.921
16	0.00184	21.06 decibels	3.973
32	4.73×10^{-4}	27.09 decibels	4.992
64	1.20×10^{-4}	33.11 decibels	5.998
127	3.03×10^{-5}	29.14 decibels	6.999
256	7.60×10^{-6}	45.16 decibels	8.000
512	1.90×10^{-6}	51.18 decibels	9.000
1024	4.76×10^{-7}	57.20 decibels	10.000

the input signal-to-noise ratio is sufficiently great so that the output noise is normally distributed about the modulating waveform as the mean value. As shown by (13)–(120) derived by Davenport and Root,[1] the output signal-to-noise ratio under high signal-to-noise ratio conditions is equal to twice the input signal-to-noise ratio for a linear detector. In other words, (7) can be assumed to hold approximately. However, the output signal contains a dc component which must be considered in arriving at the required input signal-to-noise ratio. In the coherent amplitude modulation case it was assumed that the signal was uniformly distributed over some interval, $-A/2$ to $A/2$, for instance. In the noncoherent case the interval normalized to the same units is 0 to A. The total output power for the coherent case is $A^2/12$, while it is $A^2/3$ for the noncoherent case. Therefore, the output signal power in the noncoherent case must be four times the output power in the coherent case for the same output noise. Hence β is

$$\beta = \frac{2}{H'} \frac{S_0}{N_0} \qquad \frac{S_i}{N_i} \gg 1. \tag{13}$$

Thus, the noncoherent amplitude modulation system used for the transmission of analog data is approximately 6 db less efficient than the coherent amplitude modulation system under high signal-to-noise ratio conditions.

For the transmission of digital data using noncoherent amplitude modulation, the output signal-to-nosie powers, assuming all levels are equally likely to be transmitted, are

$$S_0 = \frac{1}{L} \sum_{i=1}^{L} (\Delta A)^2 (i-1)^2 = \frac{(L-1)(2L-1)}{6} (\Delta A)^2, \tag{14}$$

$$N_0 = \sigma^2 = \frac{(\Delta A)^2}{4z^2}. \tag{15}$$

Assuming that (7) holds (*i.e.*, the input signal-to-noise ratio is large), (14) and (15) may be combined to give

$$\frac{S_i}{N_i} \simeq \frac{1}{2} \frac{S_0}{N_0} = \frac{(L-1)(2L-1)}{3} z^2. \tag{16}$$

α is given by (8); therefore, from (4),

$$\beta \simeq \frac{(L-1)(2L-1)}{3H'} z^2. \tag{17}$$

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[1] W. B. Davenport, Jr. and W. L. Root, "An Introduction to the Theory of Random Signals and Noise," McGraw-Hill Book Co., Inc., New York, N. Y.; 1958.

Thus, for the transmission of digital data the comparison of noncoherent and coherent amplitude modulation systems gives

$$\beta_{\text{noncoherent}} \simeq \frac{2(2L-1)}{L+1}\,\beta_{\text{coherent}} \qquad \frac{S_i}{N_i} \gg 1. \tag{18}$$

This result agrees closely with the more exact derivation of β for the particular case of noncoherent pulse code modulation given previously. In (18) for $L=2$, it is seen that β for the noncoherent system is twice that for the coherent system. The previous analysis showed that the ratio should be 2.21. It is also interesting to note from (18) that as the number of levels increase, the difference between noncoherent and coherent amplitude modulation systems approaches 6 db, the amount by which the noncoherent and coherent analog amplitude modulation systems differ. The β values for noncoherent amplitude modulation systems are plotted in Figs. 1–4.

FREQUENCY MODULATION

An analysis similar to the amplitude modulation case can be carried out for a frequency modulation system using conventional pulse counting discriminators. In the following discussion, formulas for transmission of analog data and of digital data are given together throughout the development since the derivations are essentially the same in both cases.

The output signal power for a signal uniformly distributed over the interval $-A/2$ to $A/2$ is $S_0=A^2/12$. In the frequency modulation case the output signal is proportional to the frequency deviation Δf of the carrier from the center frequency. Thus, for $A=\Delta f$,

$$S_0 = \frac{(\Delta f)^2}{3}\,. \tag{19}$$

For a uniformly distributed quantized signal the output power by (77) in Appendix I is

$$S_0 = \frac{(\Delta A)^2}{12}(L^2-1) = \frac{(\Delta f)^2}{3}\,\frac{L^2-1}{L^2} \tag{20}$$

where

$$\Delta A = \frac{2\Delta f}{L}.$$

The output noise power N_0 in the same units for large signal-to-noise ratios (*i.e.*, greater than the threshold value of approximately 16) in pulse type discriminators is

$$N_0 = \frac{\epsilon^2 B_d^3}{3S_i} \qquad \frac{S_i}{N_i} > 16, \tag{21}$$

where B_d is the data bandwidth, ϵ^2 is the noise spectral density, and S_i is the input signal power. Therefore, the output signal-to-noise ratios for continuous and quantized systems are the following:

continuous,

$$\frac{S_0}{N_0} = 2k\left(\frac{\Delta f}{B_d}\right)^3\left(\frac{S_i}{N_i}\right) \qquad \frac{S_i}{N_i} > 16; \tag{22}$$

quantized,

$$\frac{S_0}{N_0} = 2k\,\frac{L^2-1}{L^2}\left(\frac{\Delta f}{B_d}\right)^3\left(\frac{S_i}{N_i}\right) \qquad \frac{S_i}{N_i} > 16; \tag{23}$$

where

$$N_i = 2k\epsilon^2\Delta f,$$

$$k = \frac{B}{2\Delta f}\,.$$

Here, B is the RF bandwidth required for proper operation of the system so that k is the ratio of the actual RF bandwidth required to twice the carrier deviation. Assuming that the output signal-to-noise ratio for the quantized case is given by (89) in Appendix I, where z is defined by (88) or (90), the input signal-to-noise ratios required may be obtained by rewriting (22) and (23), making the suitable substitutions for the quantized case:

continuous,

$$\frac{S_i}{N_i} = \frac{1}{2k}\left(\frac{B_d}{\Delta f}\right)^3\frac{S_0}{N_0} \qquad \frac{S_i}{N_i} > 16; \tag{24}$$

quantized,

$$\frac{S_i}{N_i} = \frac{L^2z^2}{6k}\left(\frac{B_d}{\Delta f}\right)^3 \qquad \frac{S_i}{N_i} > 16; \tag{25}$$

where

$$P_e' = \frac{2(L-1)}{L}\,\Phi(-z). \tag{88}$$

The ratio of RF bandwidth to information rate α for both the continuous and quantized cases is

$$\alpha = \frac{2k\Delta f}{2B_dH'} = k\left(\frac{\Delta f}{B_d}\right)\frac{1}{H'}\,. \tag{26}$$

From (4), β for the two cases may be written as the following:

continuous,

$$\beta = \frac{1}{2H'}\left(\frac{B_d}{\Delta f}\right)^2\left(\frac{S_0}{N_0}\right) \qquad \frac{S_i}{N_i} > 16; \tag{27}$$

quantized,

$$\beta = \frac{L^2z^2}{6H'}\left(\frac{B_d}{\Delta f}\right)^2 \qquad \frac{S_i}{N_i} > 16. \tag{28}$$

It might appear from these equations that β can be made arbitrarily small by choosing the data bandwidth to be much smaller than the deviation; however, this can only be carried to the extent that the input signal-to-noise ratio remains above the frequency modulation threshold. From (24) and (25) it is seen that the ratio of data bandwidth to deviation is limited. Further, it might appear that β is independent of k; however, this is true only to the extent that the signal-to-noise ratio exceeds the threshold. Again from (24) and (25) the values of k are limited. If a frequency modulation system is operated at threshold, computation of β is comparatively simple. Assuming the threshold to exist at an input signal-to-noise ratio of 16, (4) shows that for both continuous and quantized cases,

$$\beta = 16\alpha, \qquad \frac{S_i}{N_i} = 16. \tag{29}$$

For a given value of α, the minimum value of β exists at this threshold. Therefore, (29) indicates the best communication efficiency possible using conventional frequency modulation discriminators.

Values of β for analog and digital sources defined in the same way as for the amplitude modulation case, using Tables I and II, are shown in Figs. 1–4.

DOUBLE FREQUENCY MODULATION

For FM/FM systems using pulse counting discriminators, the preceding analysis for a single frequency modulation channel provides the basis of analysis for each FM/FM subcarrier. If the input signal-to-noise ratios can be computed for each subcarrier discriminator, the required input signal-to-noise ratio for the carrier discriminator can be computed by making the assumption that linear superposition of each subcarrier occurs. A frequency modulation discriminator, followed by a band-pass filter where the discriminator input is a carrier modulated by a sine wave of a frequency which falls within the filter bandwidth, provides an output signal-to-noise ratio of

$$\left(\frac{S_0}{N_0}\right)_j = 12\left(\frac{S_i}{N_i}\right)\frac{k\Delta f(\Delta f_j)^2}{(2k_j'\delta_{s_j})^3}\,\frac{1}{1+3\left(\dfrac{f_{s_j}}{k_j'\delta_{s_j}}\right)^2} \qquad \frac{S_i}{N_i} > 16, \tag{30}$$

where S_i/N_i is the input signal-to-noise ratio, Δf_j is the carrier deviation due to sine wave, ϵ^2 is the input noise spectral density, $2k_j'\delta_{s_j}$ is the band-pass filter bandwidth, and f_{s_j} is center frequency. The quantity k_j' is the ratio of bandwidth required in the band-pass filter to twice the subcarrier deviation for a particular subcarrier; $2k\Delta f$ is the total RF bandwidth at the input of the discriminator.

From (24) and (25) the required signal-to-noise ratios at the input of the jth subcarrier discriminator are the following:

continuous,

$$\left(\frac{S_i}{N_i}\right)_j' = \frac{1}{2k_j'}\left(\frac{B_{d_j}}{\delta_{s_j}}\right)^3\left(\frac{S_0}{N_0}\right)_j' \qquad \left(\frac{S_i}{N_i}\right)_j' > 16; \tag{31}$$

quantized,

$$\left(\frac{S_i}{N_i}\right)_j' = \frac{L_j^2 z_j^2}{6k_j'}\left(\frac{B_{d_j}}{\delta_{s_j}}\right)^3 \qquad \left(\frac{S_i}{N_i}\right)_j' > 16. \tag{32}$$

The primes in the preceding formulas indicate signal-to-noise ratios referred to the subcarriers. If the deviation of the main carrier by each subcarrier is reasonably small, superposition can be assumed to hold so that the output signal-to-noise ratio given by (30) is equal to the subcarrier input signal-to-noise ratios given by (31) and (32). Therefore, the required input signal-to-noise ratio for the main carrier is the following:

continuous,

$$\frac{S_i}{N_i} = \frac{k_j'^2}{3k}\,\frac{B_{d_j}^3}{\Delta f(\Delta f_j)^2}\left[1+3\left(\frac{f_{s_j}}{k_j'\delta_{s_j}}\right)^2\right]\left(\frac{S_0}{N_0}\right)_j' \qquad \frac{S_i}{N_i} > 16 \qquad \left(\frac{S_i}{N_i}\right)_j' > 16; \tag{33}$$

quantized,

$$\frac{S_i}{N_i} = \frac{L^2 z_j^2 k_j'^2}{9k}\,\frac{B_{d_j}^3}{\Delta f(\Delta f_j)^2}\left[1+3\left(\frac{f_{s_j}}{k_j'\delta_{s_j}}\right)^2\right] \qquad \frac{S_i}{N_i} > 16 \qquad \left(\frac{S_i}{N_i}\right)_j' > 16. \tag{34}$$

To compute the minimum value of β, it is again true that the system should be operated at threshold; however, thresholds now exist for not only the carrier discriminator but also for each subcarrier discriminator. An optimum FM/FM system is one where all thresholds are reached simultaneously. When this is the case, it is again true that $\beta = 16\alpha$. The quantity α for an FM/FM system with n subcarriers is

$$\alpha = \frac{k\Delta f}{\sum_{j=1}^{n} B_{d_j} H_j'}\,. \tag{35}$$

Although it is difficult to plot general curves for FM/FM systems, it is instructive to compute β for such a system assuming the IRIG standards apply. For these systems, $\delta_{s_j}/f_{s_j} = 0.075$ and $\delta_{s_j}/B_{d_j} = 5$, assuming a guard band of 30 per cent for each subcarrier $k_j' = 1.3$. Utilizing (31), it can be shown that at threshold for each subcarrier, the output signal-to-noise ratio is approximately 32 db. From Table I it is seen that this signal-to-noise ratio corresponds to approximately 5 bits per sample. Assuming that $\Delta f_j = c(f_{s_j})^{3/2}$ so that all subcarriers reach threshold at the same carrier signal-to-noise ratio, β may be computed using (35), assuming that the carrier discriminator threshold occurs at the same point as that for the subcarrier threshold. In conventional FM/FM systems, $k\Delta f$ is approximately 125 kc. Further, $\sum B_{d_j} = 4000$ cps for an 18-channel telemetry system. Using these figures, $\alpha = 6.25$, yielding a β of 100. Actually, with this carrier deviation the carrier discriminator reaches threshold at a higher signal level than that required for the subcarriers. Thus, the information rate is theoretically higher than 5 bits per sample in each subcarrier. However, in practice, due to cross-modulation products and system nonlinearities, the output signal-to-noise ratio at carrier threshold is not appreciably higher than that assumed. If the system is adjusted so that the carrier deviation is set for simultaneous thresholding of carrier and subcarrier discriminators, the theoretically best value of β is approximately 64.

FREQUENCY MODULATION WITH PHASE-LOCK-LOOP RECEIVERS

The analysis of this section is restricted to FM and FM/FM systems utilizing receivers with second-order phase-lock-loop filters. That is, referring to Fig. 5, the loop filter functions for a linearized phase-lock loop are[2]

$$F_1(s) = \frac{2\zeta + 2\zeta s}{Gs}, \tag{36}$$

$$F_f(s) = \frac{2\zeta^2}{s} \cdot \tag{37}$$

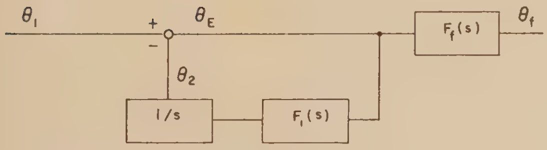

Fig. 5—Simplified block diagram of a phase-lock loop.

The resulting loop transfer functions are

$$Y_L(s) = \frac{\theta_2(s)}{\theta_1(s)} = \frac{2\zeta^2 + 2\zeta s}{2\zeta^2 + 2\zeta s + s^2}, \tag{38}$$

$$Y_E(s) = \frac{\theta_E(s)}{\theta_1(s)} = \frac{s^2}{2\zeta^2 + 2\zeta s + s^2}, \tag{39}$$

$$Y_f(s) = \frac{\theta_f(s)}{\theta_1(s)} = \frac{2\zeta^2 s}{2\zeta^2 + 2\zeta s + s^2} \cdot \tag{40}$$

In the above equations

$$\zeta = \frac{4B_L}{3}, \tag{41}$$

where

$$B_L = \frac{1}{2\pi j}\int_0^{j\infty} |\, Y_L(s)\,|^2 ds. \tag{42}$$

For an input noise spectral density (normalized by signal power) Φ_n rad^2/cps which is uniformly distributed in frequency (white noise), the mean square (steady-state) phase and frequency error for $\theta_1(t) = 0$ are

$$\sigma_p^2 = \lim_{T\to\infty} \frac{1}{2T}\int_{-T}^{T} \theta_E^2(t)dt = \frac{1}{2\pi j}\int_{-j\infty}^{j\infty} \Phi_n |\, Y_L(s)\,|^2 ds$$
$$= \frac{3}{2}\,\Phi_n\zeta = 2\Phi_n B_L \quad \text{rad}^2 \tag{43}$$

$$\sigma_f^2 = \lim_{T\to\infty} \frac{1}{2T}\int_{-T}^{T} \theta_f^2(t)dt = \frac{1}{2\pi j}\int_{-j\infty}^{j\infty} \Phi_n |\, Y_f(s)\,|^2 ds$$
$$= \Phi_n\zeta^3 = \frac{64}{27}\,\Phi_n B_L^3 \quad \text{rad}^2/\text{sec}^2. \tag{44}$$

From (42), the noise bandwidth of the phase-lock loop is B_L. The 3-db bandwidth may be calculated from (39). It is found to be $\zeta\sqrt{2(2+\sqrt{5})} \simeq 0.6177 B_L$. However, the noise bandwidth and 3-db bandwidth of the frequency output of the phase-lock loop are not the same as for the phase output. For a constant deviation sine-wave modulated frequency source $\theta_1(t) = (\sin \omega_m t)/\omega_m$, the frequency response (power) is

$$\left| \frac{1}{s} \cdot Y_f(s) \right|^2 .$$

Therefore, the noise bandwidth f_L of the frequency output of the phase-lock loop is

$$f_L = \frac{1}{2\pi j}\int_0^{j\infty} \left| \frac{4\zeta^4}{s^4 + 4\zeta^4} \right| ds = \frac{\zeta}{4} = \frac{B_L}{3} \cdot \tag{45}$$

The 3-db bandwidth is

$$f_0 = \frac{\zeta\sqrt{2}}{2\pi} = \frac{2\sqrt{2}}{3\pi}\, B_L \simeq 0.3 B_L. \tag{46}$$

From the fundamental definition of β it follows that

$$\beta = \frac{1}{2\Phi_n H} = \frac{1}{4\Phi_n B_d H'} \cdot \tag{47}$$

Using (43), this becomes

$$\beta = \frac{1}{2\sigma_p^2 H'}\left(\frac{B_L}{B_d}\right). \tag{48}$$

The restriction on the value of σ_p is dictated by the required proability of the phase-lock loop remaining in lock. Where the drop-out probability is P_p and an unmodulated carrier is present at the input,

$$\sigma_p^2 = \frac{\pi^2}{4 z_p^2} \tag{49}$$

where

$$P_p = 2\Phi(-z_p) = \sqrt{\frac{2}{\pi}}\int_{-\infty}^{-z_p} e^{-x^2/2} dx.$$

The ratio B_L/B_d and the quantity z_p are restricted by the allowed transient error in the phase-lock loop. The phase of the incoming signal must change slowly enough to allow the loop to follow.

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[2] R. Jaffe and E. Rechtin, "Design and performance of phase-lock circuits capable of near-optimum performance over a wide range of input signal and noise levels," IRE TRANS. ON INFORMATION THEORY, vol. IT-1, pp. 66–76; March, 1955.

For an input signal which is a frequency ramp with slope $\Delta\dot{\omega}$ rad/sec^2,

$$\theta_1(t) = \tfrac{1}{2}(\Delta\dot{\omega})t^2,$$

$$\theta_1(s) = (\Delta\dot{\omega})/s^3.$$

The loop error signal $\theta_E(t)$ for this input is

$$\theta_E(t) = \frac{(\Delta\dot{\omega})}{2\zeta^2}\left[1 + \sqrt{2}e^{-\zeta t}\sin\left(\zeta t - \frac{3\pi}{4}\right)\right].$$

The maximum of this expression occurs at $\zeta t = \pi$. Labeling this maximum ξ, it is

$$\xi = \frac{(\Delta\dot{\omega})}{2\zeta^2}(1 + e^{-\pi}) \simeq \frac{\Delta\dot{\omega}}{2\zeta^2} \text{ rad.} \tag{50}$$

If the input signal is band-limited of bandwidth B_d with amplitude of frequency deviation uniformly distributed over an interval $-\Delta f$ to Δf, the signal waveform may be represented as a sum of sin x/x waveforms spaced $\frac{1}{2}B_d$ seconds apart. For two successive data points of amplitude $+\Delta f$ and $-\Delta f$, the peak slope of the waveform between the two data points is $16B_d\Delta f/\pi$. On the other hand, for a triangular waveform between the two data points, the slope is $4B_d\Delta f$. Therefore, from (50), the peak transient error ξ is bounded by

$$\frac{4\pi B_d\Delta f}{\zeta^2} < |\xi| < \frac{16B_d\Delta f}{\zeta^2} \tag{51}$$

for signals of amplitude limited to $\pm\Delta f$ and of bandwidth B_d. Assuming that the lower bound holds closely enough for purposes of analysis,

$$B_d\Delta f \simeq \frac{\zeta^2}{4\pi} = \frac{4}{9\pi}B_L{}^2\xi. \tag{52}$$

If B_d is chosen to be equal to the 3-db bandwidth of the frequency output of a phase-lock loop where ζ for the filter is $\zeta = 4B_L/3$, *i.e.*, $B_d = f_0$ in (46), it follows that

$$B_d\Delta f \simeq \frac{4}{9\pi}\left(\frac{3\pi B_d}{2\sqrt{2}}\right)^2\xi = \frac{\pi}{2}B_d{}^2\xi$$

or

$$\frac{\Delta f}{B_d} \simeq \frac{\pi}{2}\xi\,\cdot \tag{53}$$

Thus, for a peak allowable transient error $\xi = 0.5$ rad, the ratio of peak deviation to information bandwidth is restricted to values less than $\pi/4 = 0.785$. As will be shown, β for such a system is relatively high.

When phase modulation is present on the input signal, (49) must be modified to take the resulting transient error into account. If a transient error ξ' rad exists, the probability P_p' that the phase noise plus transient error is greater than $\pm\pi/2$ radians is

$$P_p' = \Phi\left(-z_p\left[1 - \frac{2}{\pi}\xi'\right]\right) + \Phi\left(-z_p\left[1 + \frac{2}{\pi}\xi'\right]\right).$$

For ξ' uniformly distributed over the interval $-\xi < \xi' < \xi$, the probability that the loop will fall out of lock is

$$P_p = \frac{1}{2\xi}\int_{-\xi}^{\xi}\left\{\Phi\left(-z_p\left[1 - \frac{2}{\pi}\xi'\right]\right) + \Phi\left(-z_p\left[1 + \frac{2}{\pi}\xi'\right]\right)\right\}d\xi'$$

or

$$P_p = \frac{1}{\xi}\int_{-\xi}^{\xi}\Phi\left(-z_p\left[1 + \frac{2}{\pi}\xi'\right]\right)d\xi'. \tag{54}$$

Although this expression is difficult to evaluate exactly, a useful lower bound exists. Since $\Phi(-z)$ and its first derivative are monotonic in magnitude decreasing functions of z (for $z > 0$), it follows that

$$\int_{z_1}^{z_2}\Phi(-x)dx > \left|\frac{\Phi^2(-z_1)}{2\Phi'(-z_1)}\right| = \frac{\Phi^2(-z_1)}{2\phi(z_1)}, \tag{55}$$

where

$$\phi(z) = \frac{1}{\sqrt{2\pi}}e^{-z^2/2},$$

under the conditions that

$$z_2 \geq z_1 + \frac{\Phi(-z)}{\phi(z)},$$

$$z_1 \geq 0.$$

Therefore,

$$P_p > \frac{\pi\left[\Phi\left(-z_p\left[1 - \frac{2}{\pi}\xi\right]\right)\right]^2}{4z_p\xi\phi\left(z_p\left[1 - \frac{2}{\pi}\xi\right]\right)}, \tag{56}$$

where

$$\frac{\pi}{2} \geq \xi \geq \frac{\pi}{4z_p}\,\frac{\Phi\left(-z_p\left[1 - \frac{2}{\pi}\xi\right]\right)}{\phi\left(z_p\left[1 - \frac{2}{\pi}\xi\right]\right)}.$$

Thus, P_p is the probability of losing lock if the transient error is uniformly distributed over an interval $-\xi$ to ξ and if the mean square phase noise is $\sigma_p{}^2 = \pi^2/4z_p{}^2$.

In order to compute β for phase-lock-loop systems, it is necessary to find an expression for H', the information transmitted per sample. This is most easily accomplished by utilizing the methods of Appendix I and the results tabulated in Tables I-III. For an input signal uniformly distributed in frequency in the interval $-\Delta f$ to Δf, the output signal-to-noise ratio, by (19) and (44), is

$$\frac{S_0}{N_0} = \frac{9\pi^2(\Delta f)^2}{16\Phi_n B_L{}^3} = \frac{9\pi^2}{4}\left(\frac{\Delta f}{B_L}\right)^3\left(\frac{S_i}{N_i}\right). \tag{57}$$

From (43), it follows that

$$\frac{S_0}{N_0} = \frac{9\pi^2}{8\sigma_p^2}\left(\frac{\Delta f}{B_L}\right)^2 \tag{58}$$

if B_L in (43) and (44) are equal. From (46) and (53) it follows that

$$\frac{S_0}{N_0} = \frac{\pi^2\xi^2}{4\sigma_p^2} = \xi^2 z_p^2. \tag{59}$$

Thus the product ξz_p is determined by the desired output signal-to-noise ratio and hence the desired information rate. Referring to Table I, it is seen that for $H'=5$, S_0/N_0 must be approximately 2000. Therefore, $\xi z_p = 44.7$. For a lock drop-out probability $P_p = 10^{-4}$, (56) may be solved to give $z_p = 30.64$ and $\xi = 1.459$ rad.

From (48),

$$\beta = \frac{1}{\sigma_p^2 H'}\left(\frac{B_L}{B_d}\right) = \frac{4z_p^2}{\pi^2 H'}\left(\frac{B_L}{B_d}\right)$$

$$= \frac{4(30.64)^2}{\pi^2(5.0)}\left(\frac{3\pi}{2\sqrt{2}}\right) = 254.$$

Such a high value of β is highly undesirable for space telemetry applications. It comes about because such a large proportion of the transmitter power must reside in the carrier or, equivalently, because the product ξz_p is so large. The question naturally arises as to methods of reducing β with phase-lock-loop systems.

One method is to modify the bandwidth of the frequency output filter $Y_f(s)$ so that the modulation index of the input signal is not restricted by (53). The set of equations which must be used to compute β in this case are summarized below:

$$\sigma_p^2 = 2\Phi_n B_L \doteq \frac{\pi^2}{4z_p^2}, \tag{43), (49}$$

$$\sigma_f^2 = \frac{64}{27}\Phi_n B_f^3, \tag{60}$$

$$f_0 = B_d = \frac{2\sqrt{2}}{3\pi} B_f, \tag{61}$$

$$B_d \Delta f \simeq \frac{4}{9\pi} B_L^2 \xi, \tag{52}$$

$$\frac{S_0}{N_0} = \frac{9\pi^2(\Delta f)^2}{16\Phi_n B_f^3} = \frac{9\pi^2}{4}\left(\frac{\Delta f}{B_f}\right)^3\left(\frac{S_i}{N_i}\right), \tag{62}$$

or

$$\frac{S_0}{N_0} = \frac{9\pi^2}{8\sigma_p^2}\,\frac{B_L}{B_f}\left(\frac{\Delta f}{B_f}\right)^2, \tag{63}$$

$$\beta = \frac{1}{2\sigma_p^2 H'}\left(\frac{B_L}{B_d}\right). \tag{48}$$

Eqs. (60)–(63) are obtained from (44), (46), (57) and (58) by replacing B_L in the latter equations by B_f. B_f is defined by revising filter functions, (37) and (40), to

$$F_f(s) = \frac{2\zeta_f^2}{s}\,\frac{2\zeta^2 + 2\zeta s + s^2}{2\zeta_f^2 + 2\zeta_f s + s^2}, \tag{64}$$

$$Y_f(s) = \frac{2\zeta_f^2 s}{2\zeta_f^2 + 2\zeta_f s + s^2}. \tag{65}$$

From the preceding equations, β may be found by simple algebraic substitutions. First using (43), (49), (52), (61), and (63) it follows that

$$\frac{S_0}{N_0} = \xi^2 z_p^2\left(\frac{B_L}{B_f}\right)^5, \tag{66}$$

or

$$\frac{B_L}{B_d} = \frac{3\pi}{2\sqrt{2}}\left(\frac{1}{z_p^2\xi^2}\,\frac{S_0}{N_0}\right)^{1/5}. \tag{67}$$

Therefore,

$$\beta = \frac{3z_p^2}{\pi\sqrt{2}H'}\left(\frac{1}{z_p^2\xi^2}\,\frac{S_0}{N_0}\right)^{1/5}, \tag{68}$$

where H' is defined from the output signal-to-noise ratio. For the analog case, (68) holds directly. For the transmission of discrete data, (68) is modified by (89) in Appendix I. In this case

$$\beta = \frac{3z_p^2}{\pi\sqrt{2}H'}\left(\frac{z_0^2}{z_p^2\xi^2}\,\frac{L^2-1}{3}\right)^{1/5}, \tag{69}$$

where z_0 is given by (88) or (90) depending on the encoding scheme.

For an output signal-to-noise ratio of 2000 and a drop-out probability, $P_p = 10^{-4}$, $\beta = 9.071$. This is a minimum value for (69) based on the foregoing assumptions including P_p evaluated from (56). Because (56) is a lower bound on P_p, the computed value of β is actually a lower bound. However, it is very close to the actual value. The other system constants which hold for this minimum value of β are $z_p = 4.311$, $\xi = 0.418$ rad, $\sigma_p = 0.364$ rad, $\Delta f/B_d = 8.57$, $B_L/B_f = 3.6147$, $\Delta f/B_L = 0.7115$, and $S_i/N_i = 5.29$ or 7.24 db.

For the transmission of digital data with $L=32$, $P_e = 10^{-6}$, and $P_p = 2.0\times 10^{-7}$, $\beta = 20.55$. In this case $z_p = 5.9519$, $\xi = 0.370$ rad, $\sigma_p = 0.264$ rad, $\Delta f/B_d = 10.72$, $B_L/B_f = 4.30$, $\Delta f/B_L = 0.749$, $S_i/N_i = 9.59$ or 9.82 db. If P_e increases to 10^{-3} and P_p to 2×10^{-4} the resulting β changes to 8.31, corresponding to a signal-to-noise input ratio of 4.61 or 6.64 db.

An additional point has been calculated for the transmission of analog data where an output signal-to-noise ratio of 67 db is required. The resulting lower bound on β in this case is approximately 57.

Comparing these results with those computed for an FM system using conventional discriminators indicates that there is actually very little difference in the β efficiency of the two techniques. This fact may be seen by referring to Fig. 2.

It is difficult to compute the β efficiency of FM/FM systems utilizing phase-lock loops for both the carrier and subcarriers. In FM/FM systems employing conventional discriminators it is seen that β is approximately 6 db higher (using IRIG standards) than in a nonfrequency-multiplexed FM system. It is unlikely that double phase-lock-loop FM/FM systems will appreciably lower the value of β over conventional discriminator FM/FM systems. Two approaches are possible for carrier phase-lock-loop systems, namely, modulation-following and nonmodulation-following systems. For nonmodulation-following systems, such as those used in present-day narrow-band Microlock, 80 to 90 per cent of the power resides in the carrier due to the upper bound imposed on the carrier modulation index to obtain necessary linearity. Such systems, as discussed previously, result in very high values of β compared to modulation-following systems. For modulation-following phase-lock loops it is reasonable to assume that the required signal-to-noise ratio for proper system operation in the loop will be between 6 and 10 db. Making this assumption and assuming that the noise bandwidth of a phase-lock loop is roughly equal to the maximum carrier deviation, the resulting value of β for an output signal-to-noise ratio of 2000 can be no less than one-half that of the conventional discriminator FM/AM equivalent system; *i.e.*, β will not be less than approximately 30.

One alternative modulation scheme which shows promise for reducing β is a frequency multiplexed FM/AM system with suppressed or partially suppressed AM carrier. Double phase-lock loops could be used in this system without the requirement of large carrier to sideband power ratios.

ORTHOGONAL SYSTEMS

According to Shannon's channel capacity theorem, β should decrease as α increases for some communication systems. From Figs. 1 and 3 it is seen that this is true for amplitude modulation; however, α cannot be made greater than approximately 2 without some sophisticated encoding process. Also from the Figs. 1 and 3 it is seen that for FM systems β increases with increasing α. In this section a fairly simple set of orthogonal communication systems are shown to exist where β decreases with increasing α for arbitrarily large α.

In general, an orthogonal communication system is defined as one for which N messages can be transmitted, each of which consists of N degrees of freedom such that (discrete) matched filters may be designed which satisfy the following equalities:

$$\text{filter outputs} = \sum_{j=1}^{N} c_{ij}c_{kj} = \begin{cases} 0 & i \neq k \\ A & i = k, \end{cases} \tag{70}$$

where

c_{rs} = values of sth degree of freedom for the rth message or matched filter.

$r, s = 1, 2, \cdots, N$.

Examples of such systems are discrete pulse position modulation and discrete frequency modulation. Another example, discussed in more detail below, is a generalized PCM system. In all cases it is assumed that sufficiently accurate timing standards and filters are available at the transmitting and receiving sites to enable synchronism to be maintained. Assuming that code lock and carrier lock can be maintained, the β efficiency of an orthogonal system depends on the type of detector employed. Since for L equiprobable messages the system possesses L outputs, it is natural to select a maximum likelihood "greatest-of" type of detector.

From (70) it is seen that if bipolar signals are used, it is possible by means of a simple phase reversal to double effectively the number of levels for the same number of degrees of freedom if an output detector is constructed to detect both $+A$ and $-A$ outputs. In the following it will be assumed that there are N degrees of freedom with $L=2N$ levels.

For square bandwidths, the bandwidth required to transmit N degrees of freedom f_n times per second is $B_n = f_nN/2$. Assuming P_e' and $L=2N$ are given, information rate can be computed from (85) so that

$$\alpha = \frac{B}{H} = \frac{f_nN}{2f_nH'} = \frac{N}{2H'} \cdot \tag{71}$$

For orthogonal systems the output signal-to-noise power ratio is N times the input signal-to-noise ratio. For a maximum-likelihood detector (see Appendix II) the input signal-to-noise ratio required to provide an error probability P_e' is

$$\frac{S_i}{N_i} = \frac{2z_N^2}{N} \tag{72}$$

where

$$\Phi(-z_N) \simeq \frac{P_e'}{2N-2} \quad P_e' \ll 1.$$

For this case,

$$\beta = \frac{z_N^2}{H'} \rightarrow \frac{z_N^2}{\log 2N} \qquad \text{for } P_e' \ll 1.$$

Since orthogonal systems are basically digital transmission systems, they must be treated somewhat differently from AM or FM systems; however, Table III, derived in Appendix I, still gives a good basis for comparison. For a desired output signal-to-noise ratio, a number of levels and associated error probability can be taken from Table III for the transmission of analog data. For the transmission of digital data, the error rate is given directly by (72). In the above formulas the number of levels L is equal to twice the number of degrees of freedom of the system; *i.e.*, $L=2N$.

One particular orthogonal system is especially attractive for space telemetry use. This is a generalized PCM system utilizing maximum redundancy Reed-Muller codes.[3]

APPENDIX I

COMPARISON OF DISCRETE AND CONTINUOUS SYSTEMS

The noise analysis of digital transmission systems generally depends on assigning some error probability per bit or per sample. In continuous systems it is convenient for comparison purposes to express rms errors in the same terms. A method of doing this is to derive an equivalent rms error for discrete systems made up of quantization error and error probability. For multilevel discrete systems with equal increments between levels, the variance of the quantization error is

$$\sigma_q^2 = \frac{(\Delta A)^2}{12} \tag{73}$$

where ΔA = amplitude difference between levels. Further, if all levels of a particular system are equally likely to be transmitted and the error probability is uniformly distributed over all nontransmitted levels (*e.g.*, as in an orthogonal system), the variance of the error due to an error probability per sample P_e' is

$$\sigma_e^2 = (\Delta A)^2 \frac{P_e' L(L+1)}{6} \tag{74}$$

where L = number of quantization levels.[4]

Assuming that the system is designed so that $k\sigma_q^2 = \sigma_e^2$ at the minimum permissible power level, it follows that

$$P_e' = \frac{k}{2L(L+1)}. \tag{75}$$

The total variance of the error is $\sigma_t^2 = \sigma_q^2 + \sigma_e^2$ or

$$\sigma_t^2 = \frac{(\Delta A)^2}{12}(1+k). \tag{76}$$

In terms of ΔA, the signal power S, assuming all levels are equally probable, is

$$S = \frac{1}{L}\sum_{i=1}^{L} (\Delta A)^2 \left(i - \frac{L+1}{2}\right)^2$$

$$= \frac{(\Delta A)^2}{12}(L^2-1). \tag{77}$$

Thus,

$$\sigma_t^2 = S\,\frac{1+k}{L^2-1}. \tag{78}$$

In other words, the equivalent signal-to-noise power ratio of a digital system with L levels and error probability per sample P_e' given by (75) is

$$\frac{S}{N} = \frac{L^2-1}{1+k}. \tag{79}$$

In the preceding equations, k is an arbitrary positive number which defines the ratio of error due to error probability and to number of quantization levels. For example, if $k=0$, (75), the error probability must be 0, and the signal-to-noise ratio is due solely to quantization error. If the quantization error and error due to error probabillty are equally effective in determining signal-to-noise ratio, $k=1$. Table III shows error probability and equivalent signal-to-noise ratio for various values of L from (75) and (79) for $k=1$.

Unfortunately, it does not follow that a comparison of information rate for continuous and quantized channels can be based on signal-to-noise ratio equivalents. Information rate for a continuous channel where the perturbing noise is independent of the transmitted signal is

$$H' = H'(y) - H'(n)$$

$$= -\int_{-\infty}^{\infty} p(y)\log_2 p(y)dy + \int_{-\infty}^{L} p(n)\log_2 p(n)dn \tag{80}$$

where

$H'(y)$ = the entropy of the received signal including noise,

$H'(n)$ = the entropy of the perturbing noise.

Assuming that the transmitted signal is uniformly distributed over an interval of $-A/2$ to $A/2$ and that the perturbing noise is normally distributed with zero mean and rms value σ, the probability distributions of the received signal and of the perturbing noise are

$$p(y) = \frac{1}{A}\left[\Phi\left(\frac{2y+A}{2\sigma}\right) - \Phi\left(\frac{2y-A}{2\sigma}\right)\right], \tag{81}$$

$$p(n) = \frac{1}{\sigma\sqrt{2\pi}} e^{-n^2/2\sigma^2}. \tag{82}$$

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[3] R. W. Sanders, "Digilock Telemetry System," presented at the National Symp. on Space Electronics and Telemetry, San Francisco, Calif.; September 28–30, 1959.

[4] Note that there are many ways of computing σ_e. It depends on the particular digital system being used and the signal and error distributions. The assumption used here of a uniform error distribution over all levels not transmitted applies to systems such as orthogonal systems. However, assuming that all levels are equally likely to be transmitted, the value of σ_e does not appear to be critically dependent on the type of digital transmission system used. For example, in a PCM system where the number of transmitted levels is a power of 2, $\sigma_e^2 = (\Delta A)^2 P_e (L^2-1)/3$ where P is the error rate per bit.

The entropy of the received signal corresponding to the first integral of (80) is

$$H'(y) = \log_2 A - \frac{\sigma}{A}\int_{-\infty}^{\infty} [\Phi(w+\gamma) - \Phi(w-\gamma)] \cdot \log_2 [\Phi(w+\gamma) - \Phi(w-\gamma)]dw \qquad (83)$$

where

$$\gamma = \frac{A}{2\sigma},$$

$$\Phi(x) = \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{x} e^{-x^2/2}dx.$$

The integral in this expression is difficult to evaluate analytically; however, its approximate value is calculable for large signal-to-noise ratios

$$H' \simeq \log_2 A - \log_2 \sigma\sqrt{2\pi e} + \frac{\sigma}{A}(2.6062)$$

$$\simeq \frac{1}{2}\log\frac{S}{N} + 0.7523\sqrt{\frac{N}{S}} - 0.2546 \qquad \frac{S}{N} > 5 \quad (84)$$

where

$$S = \frac{A^2}{12},$$

$$N = \sigma^2.$$

In order to compare continuous and discrete transmission systems on the basis of equal information rates, it is necessary to calculate the transmission rate per sample for a discrete channel. For such a system, which transmits L levels with an error probability P_e' per sample and where all levels are equally likely to be transmitted and all levels are equally likely to be chosen if an error occurs, the information rate per sample is[5]

$$H' = \log_2 L - P_e' \log_2 (L-1) + P_e' \log_2 P_e' + (1 - P_e')\log_2(1 - P_e'). \qquad (85)$$

For P_e' defined from (75), H' becomes

$$H' = \log_2 L - \frac{k}{2L(L+1)}[\log_2 (L-1)(2L^2 + 2L - k)]. + \log_2(2L^2 + 2L - k) - \log_2(2L^2 + 2L). \qquad (86)$$

For $k=1$, this equation reduces to

$$H' = \log_2 L - \frac{1}{2L(L+1)}[\log_2 (L-1)(2L^2 + 2L - 1)] + \log_2(2L^2 + 2L - 1) - \log_2(2L^2 + 2L). \qquad (87)$$

The value of H' given by (87) for a digital system, where the rms output errors due to quantization and due to transmission error rate are equal, is given in Table III. S/N in Table I has been computed from (84), assuming that the signal-to-noise ratio of a continuous channel is defined to provide transmission rates equivalent to the rates for the digital channels shown in Table III. For example, from the fourth entry in Table III it is seen that a signal-to-noise ratio of 27.09 db is required to transmit 4.992 bits per sample, the amount of information transmitted per sample in a digital system of 32 levels with an error rate P_e' of 4.73×10^{-4} per sample. It is seen, comparing the results of Table III and Table I, that a considerable difference exists in the output signal-to-noise ratios for continuous and discrete systems under the assumed conditions for equivalent information rates. Qualitatively, the reason for this is that a continuous channel makes comparatively small mistakes most of the time while the discrete channel makes comparatively large mistakes less frequently. This statement may be further elucidated by computing a probability of error for the continuous channel which can be compared with that for a discrete channel.

If a continuous channel is divided into L increments, each of magnitude ΔA, and the noise in the channel appears as the linear addition of Gaussian noise to the signal, the probability of error $P_e'(i)$ per sample for all levels except the first and last is

$$P_e'(i) = 2\Phi(-z) \qquad i = 2, 3, \cdots, L-1$$

where

$$z = \frac{\Delta A}{2\sigma},$$

$$\sigma^2 = \text{noise power},$$

$$\Phi(-z) = \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{-z} e^{-x^2/2}dx.$$

For the first and last levels

$$P_e'(i) = \Phi(-z) \qquad i = 1, L.$$

Assuming all levels are equally likely to be transmitted, the average error rate per sample is

$$P_e' = \frac{2}{L}\Phi(-z) + \frac{L-2}{L}[2\Phi(-z)] = \frac{2(L-1)}{L}\Phi(-z). \qquad (88)$$

Still assuming that all levels are equally likely to be transmitted and that the mean value of signal is zero, the average signal power is given by (77),

$$S = \frac{(\Delta A)^2}{12}(L^2 - 1).$$

Since $z^2 = (\Delta A)^2/4\sigma^2$, the output signal-to-noise ratio required for an error rate defined by (88) is

$$\frac{S}{N} = \frac{L^2 - 1}{3} z^2. \qquad (89)$$

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[5] Based on the entropy definition of information. See C. E. Shannon and W. Weaver, "The Mathematical Theory of Communication," University of Illinois Press, Urbana, Ill.; 1949.

Using (89) to define z from the signal-to-noise ratios shown in Table I for the various discrete channels with L levels, P_e' for the continuous systems can be computed from (88). The results of such computations are given in Table I. From these computations the above qualitative statement may be interpreted more precisely. For example, again taking the fourth entry of Table I, it is seen that the continuous channel, if used in a discrete application, would commit an error in the discrete sense once each 24 samples. In the analog sense, each error, while significant, still has a high probability of being within a few standard deviations of the correct value. For the equivalent digital system an error other than quantization error is committed only once for each 2100 data samples; however, when an error is committed, there is no assurance that the resulting analog output is close to the transmitted value.

The preceding analysis provides a method for comparing analog and digital transmission of *analog* data. By interpolating between the entries of Table I, the comparison can be made by defining an information rate for the analog data based on a desired signal-to-noise ratio. This same information rate can be transmitted by a digital channel in a number of ways. By interpolating between the entries of Table III, a digital channel can be defined which will transmit at the same information rate as the analog system where it is assumed that the digital system error rate is fixed at a level which will cause the output analog error due to digital quantization to be equal to the analog error due to transmission error rate.

The analysis of analog and digital transmission systems may be completed by investigating more thoroughly the analog and digital transmission of *digital* data. An analog transmission channel may be used to transmit digital data by quantizing the analog channel into a given number of levels and adjusting the signal-to-noise ratio so that the probability of error between levels is a prescribed amount. Assuming that the levels are equidistant and that the noise in the output appears as a linear addition of Gaussian noise to a signal, the average probability of error per sample is given by (88). The required output signal-to-noise ratio is given by (89). Qualitatively, this comparison of analog and digital systems assumes that any error is equally bad and that information rate for either type of transmission is defined in terms of channel error probability.

In order to define error rate in terms of error per bit for digital transmission using quantized continuous channels, it is necessary to postulate the method of assigning binary numbers to each level. The smallest bit error rate occurs if a Gray code is used so that adjacent levels differ by only one binary position. In this case, assuming that the per sample error rate is small, the error per bit P_e is

$$P_e = P_e'/\log_2 L.$$

Therefore, bit error rate for an analog channel transmitting Gray coded digital data is

$$P_e = \frac{2(L-1)}{L \log_2 L} \Phi(-z). \tag{90}$$

Values of analog signal-to-noise ratios required for a bit error rate of 10^{-6} are shown for various numbers of levels in Table II.

APPENDIX II

MAXIMUM LIKELIHOOD DETECTOR ORTHOGONAL SYSTEM ERROR RATES

From the sampling theorem, there are $N=2BT$ degrees of freedom in a message of bandwidth B and of duration T. For an orthogonal system of $L=2N$ levels, the signaling rate for small error probability P_e' is

$$H = \frac{1}{T}\log L = \frac{4B}{L}\log L.$$

For a fixed bandwidth, the signaling rate for $L=2$ is equal to the rate for $L=4$. Therefore, a 4-level orthogonal system is equivalent to a 2-level PCM system. In a linear PCM system with two equiprobable states, a maximum likelihood detector is one which is defined by a suitably designed threshold. Assuming a "0" sent is represented by $+S$ volts and a "1" by $-S$ volts, the maximum likelihood threshold is 0 volts. Any detector output which is positive is taken to be a "0"; negative outputs are taken as "1's." In a 4-level orthogonal system there are two output busses. If signal components s_1, s_2 and noise components n_1, n_2 are received, the output from each bus γ_1 and γ_2 is

$$\gamma_1 = s_1 + s_2 + n_1 + n_2. \qquad s_1, s_2 = \pm S$$
$$\gamma_2 = s_1 - s_2 + n_1 - n_2.$$

The outputs from γ_1 under noise-free conditions are $2S$, 0, 0, $-2S$ for codes 00, 01, 10, 11 in. The corresponding γ_2 outputs are 0, $2S$, $-2S$, 0. The error performance of the system is independent of the code which is sent. Assuming 00 is transmitted, an error will be committed by a "greatest-of" detector; *i.e.*, a detector which chooses the largest buss output magnitude at the most probable transmitted signal, if and only if

$$2S + n_1 + n_2 < |n_1 - n_2|. \tag{91}$$

This inequality holds only if $n_1 < -S$ or if $n_2 < -S$ or both. Therefore, a 4-level orthogonal system with a "greatest-of" detector is equivalent to a PCM system with a maximum likelihood detector.

For a PCM signal disturbed by Gaussian noise, the probability of an error P_{e_1} being made is $\Phi(-Z)$ where z is the signal-to-noise ratio S/σ^2 and $\Phi(-z)$ is the normal distribution function. Thus, the probability of error P_{e_2} for a 4-level orthogonal system is

$$P_{e_2} = 1 - \Phi^2(z).$$

Therefore, from (91),

$$\Pr\,(2S + N_{21} < |N_{22}|) = 1 - \Phi^2(z), \qquad (92)$$

where

$$N_{21} = n_1 + n_2,$$
$$N_{22} = n_1 - n_2.$$

If n_1, n_2 are independent random variables of standard deviation σ, N_{21} and N_{22} are also independent random variables but with standard deviation $\sigma\sqrt{2}$. Letting $S^* = 2S$, $N_1^* = N_{21}$, and $N_2^* = N_{22}$, it follows from (92)

$$P_{e_2} \Pr\,(S^* + N_1^* < |N_2^*|) = 1 - \Phi^2\left(\frac{z^*}{\sqrt{2}}\right), \qquad (93)$$

where

$$z^{*2} = \frac{4S^2}{2\sigma^2} = E\left(\frac{S^{*2}}{N_1^{*2}}\right) = 2z^2.$$

For an L-level orthogonal system $(L-2N)$, the error probability for a "greatest-of" detector is

$$P_{e_N} = 1 - \int_0^\infty \phi(x - z_N^*)\,[\Phi(x) - \Phi(-x)]^{N-1}dx \qquad (94)$$

where

$$z_N^* = z\sqrt{N}.$$

By expanding (94) and making use of (93) it follows that

$$P_{e_N} \leq 1 - (N-1)\Phi^2\left(\frac{z^*}{\sqrt{2}}\right) + (N - z)\Phi(z^*)$$
$$\simeq 2(N-1)\Phi\left(-\frac{z^*}{\sqrt{2}}\right) z^* \gg 1.$$

Therefore,

$$\alpha = \frac{B}{H} = \frac{N}{2\log 2N} = \frac{L}{4\log L} \qquad (L > 2),$$

$$\beta = z^2\alpha = \frac{z^{*2}}{2\log 2N} = \frac{z_N^2}{\log 2N} = \frac{z_N^2}{\log L}, \qquad (95)$$

where

$$z_N = \frac{z^*}{\sqrt{2}},$$

$$\Phi(-z_N) = \frac{P_{e_N}}{(2N-1)} = \frac{P_{e_N}}{L-2} \qquad (L > 2).$$

A plot of (95) is shown in Fig. 6. By a detailed analysis of (94) it can be shown that β approaches $\log_e 2$ as n approaches infinity for an arbitrarily small P_{e_N}.

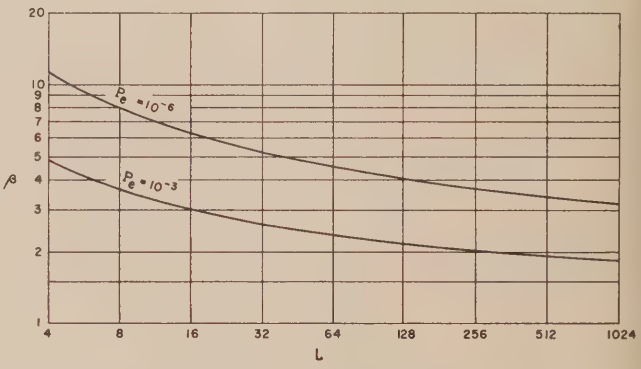

Fig. 6—Communication efficiency β of the orthogonal systems as a function of the number of levels L for bit error rate P_e of 10^{-3} and 10^{-6}.

Maximum Utilization of Narrow-Band Data Links for Interplanetary Communications*

W. F. SAMPSON†, SENIOR MEMBER, IRE

Summary—Our ability to communicate with vehicles in space continues to be limited by the amount of received energy required to transmit a unit of information to earth. We have available, in practical hardware, radio-communication systems which provide us with theoretical maximum performance in terms of data bandwidth and distortion for a given transmission range and power output. The development and refinement of transmission, receiving, and power-supply techniques will extend the range of communication or increase the data bandwidth at a given range; but any significant extension of our capacity to communicate in space must come from advances in the state-of-the-art of telemetry data handling. New and advanced means for data processing and encoding prior to transmission should be investigated.

The discussion which follows defines some technical areas which merit investigation, presents an outline for one approach to such an investigation and contemplates the evaluation of findings.

INTRODUCTION

THE PROBLEM facing those wishing to make physical or physiological experiments in unusual environments is the collection, transmission and interpretation of experimental data. The problem extends from the collection of data at primary sensors, through a sequence of data processing and transmission steps, and ends at the final interpretation of the experimental result, usually in a written report. Current practice in this process is well known and need not be reiterated here; however, we do not know where, in detail, we may improve on current practice. One area which seems to promise the next great advance in telemetry is the detection and coding for efficient transmission of basic data, at low-energy levels, which has been severely contaminated by noise.

An evaluation of the present state-of-the-art of sensors and data links is of interest in determining requirements or opportunities for improvements, based on detection and signal processing. We may postulate: if data links of any desired performance (bandwidth, range, linearity, distortion) were available, there would be no requirement for data detection prior to transmission and only distortionless amplification would be required. That is, if we could receive at the fixed ground station all of the original sensor output, we would be able to process the data at leisure, bringing to bear all the most advanced technology of data processing (digital computers). The foregoing statement does not remove the necessity to study methods for recovery of the desired data from relatively intense noise. A requirement for the development of advanced sensors and data links exists, but the characteristics of available data links will determine what portion of the data processing techniques to be developed should profitably be accomplished prior to data transmission by the telemetry radio link.

If such processing functions can be accomplished in reliable equipment with suitable environmental immunity, it appears possible to achieve additional gain in information from experiments which are currently limited by the capabilities of the radio link. Conversely, we may be able to perform, with a given vehicle which is weight- or power-limited, additional types of experiments which also result in a net increase in the amount of knowledge gained from each vehicle.

DATA HANDLING SEQUENCE

The information flow for a single experiment is illustrated in Fig. 1. In this figure, the progression of data from sensor to report is defined by the independent variable, x. The on-board (preliminary) and ground data reduction steps are separated by a data link, the only function of which is to transfer all of the information in existence at x_0 from one physical location to another.

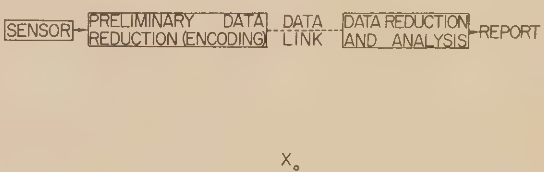
SENSOR
PRELIMINARY DATA REDUCTION (ENCODING)
DATA LINK
DATA REDUCTION AND ANALYSIS
REPORT
X₀
X

Fig. 1—Information flow.

As the signals, which contain the results of the experiment, progress down the line of information flow, they are modified progressively to enhance the desired data and to average out random errors and correct for identifiable systematic errors. Throughout this process, the information content, in the entropy sense, may be considered to be constant and equal to the information desired for the final report. Any redundant data carried along at any point in the process represent unnecessary data as far as the final report is concerned, and the transmission of such redundant data on the data link results in a demand for extra bandwidth over the minimum requirement for the fundamental information. We hope, in addition, that the redundancy content is at least equal to the noise and error content so that this redundancy can be used, as the data reduction process continues, to remove the noise and enhance the signal to the desired degree. Thus, for a potentially successful experiment, the bandwidth required at any given transfer point x_0 must be equal to or greater than the remaining signal redundancy plus information entropy.

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* Original manuscript received by the IRE, November 23, 1959.

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Elements for Preliminary Investigation

The characteristics of input transducers or sensors must be studied and tabulated. The nature of the output signal and the manner in which this signal represents the final desired data must be understood. We should search for potential sources of noise and systematic errors and obtain mathematical descriptions of these, where feasible. A detailed knowledge of these factors is essential before any discussion of optimum data reduction processes.

There may be certain physical limits to the detectability of the desired final data. One obvious limit is the quantum effect, which probably does not come into play in the majority of the experiments to be considered. Another limit is the result of random noise and is usually expressed in terms of noise bandwidth compared to signal bandwidth or information content. This concept is not limited to linear processes but can be extended to nonlinear processes as well, provided appropriate definitions are made of noise bandwidth and information content. These, and other, physical limits to detectability must be carefully stated and understood in order to avoid attempting the impossible. This is one of the most important "negative" results of information theory, one which has been of great importance in the practical design of communication systems.

We may define two classes of signal handling processes, one of which is allowable for inclusion in an optimum system. This first class is characterized by the fact that the ratio of noise power to remaining redundancy and information content is never greater at the output than at the input. In other words, the basic detectability of the desired data is unchanged. A perfect linear amplifier is obviously a member of this class, as are the usual correlation techniques. The net result of processing a signal through a sequence of such allowable operations is the recovery of the desired information with maximum signal-to-noise ratio as defined by the basic statement of detectability.

The second class of signal handling processes violates the requirement that the detectability of the signal be not reduced by the inclusion of the process. One such process is square-law or envelope detection of a signal at less than unity signal-to-noise ratio. Certain digital sampling processes may also be forbidden.

By investigating and tabulating the allowed and nonallowed signal handling processes, we hope to gain an insight into practical system designs for optimum detection. Of particular importance is the "negative" result than any optimum data-processing device must not include any process of the second class.

In the development of practical detection and encoding equipment and in the integration of such equipment into an optimum data system, an understanding of the basic characteristics of data links is a prerequisite. As stated previously, the present theoretical and practical limits of data links are the only justification for any consideration of additional data handling equipment to be included in the vehicle prior to data transmission. In fact, these current limitations are the determining factor in any decision relative to how much equipment is to be included in the vehicle.

The foregoing preliminary investigations would serve to summarize and codify present knowledge in a form applicable to the problem at hand. Some of the basic results of information theory, when restated in appropriate form for ready reference, would serve as a guide to the identification of those portions of the present art which already approach theoretical maximum performance. Concurrently, we should expect to identify areas wherein greatest improvement is feasible, because present art falls significantly short of predicted potential performance. For the direction of further studies, primary efforts should be concentrated where the greatest gain is available.

Concepts of Optimum Data Reduction

Reduced Redundancy

There is obviously no requirement for duplicate or redundant statements of the same datum by the time information appears in the final report, which is the end of the experiment—data reduction sequence. By lack of redundancy in the final statement of the datum, we mean that any further boiling down or condensation of the statement would change its meaning in an irretrievable manner. If such a nonredundant statement of a datum has been achieved by a series of allowable data reduction processes which do not degrade the theoretically attainable signal-to-noise ratio, then we must have realized the maximum possible improvement in the data. This principle can be used as a guideline to produce practical equipment for optimum data reduction, and the principle serves to identify the endpoint of the process.

We must recognize that a datum is still redundant if it contains any *a priori* information. Reducing the redundancy of a statement by removal of previously known facts may change the visible character of the statement, but not irretrievably, since we may always reconstruct that which we already knew before the experiment was performed. The maximum utilization of *a priori* information is the keystone to any correlation-detection process.

Although we may boil all the redundancy out of a datum, its value as information may not be very high if we could have predicted with high probability the result of the experiment. The information content is actually inversely proportional to the probability of occurrence of the observed datum. Surprises are worth the struggle, but mere reconfirmation of an expected result is of little value. Consequently, an aim of data reduction prior to transmission or prior to reporting should be to smooth out or equalize the surprise content of each datum communicated. We can most efficiently use the communication channel by transmitting continuously, at maximum rate, data which are uniformly high in information content. (It should be noted that the final written report is probably the narrowest information channel in the whole chain.)

In our zeal to wring all possible redundancy from a datum before reporting it, we may go too far. A completely nonredundant statement may well be too compressed for understanding by anyone other than the designers of the experiment. As an example, suppose we are to report electrocardiograms from deep space. The correlation detection might be in the form of a set of matched filters which produce output pulses, sorted to appropriate wires, with each characteristic beat of the heart. The transmitted data might be a series of numbers indicating the frequency of occurrence of pulses from each of the filters. Pulses representing normal heart operation would be merely reported as present, but abnormal or "surprise" pulses would be reported in detail. Such a report contains all the data in a nonredundant form and has been arranged to appropriately weight surprise data; however, the report may be unintelligible to an experienced doctor who would prefer to read the actual ECG waveforms and make his own interpretation from experience.

It is certainly feasible to regenerate "example" waveforms based on the nonredundant received data. The normal pulses would be written repeatedly at the reported rate, and the abnormal pulses interjected as instructed by the received data. Such an example waveform would not be guaranteed to be identical to the original gauge output, but it would contain exactly the same nonredundant data. The necessity or desirability of such regeneration of "example" waveforms is based on our own psychological desire to approximate the physiological impressions we might have received by performing the experiment directly, thereby gaining a better understanding of what occurred.

The maximum-likelihood concept of correlation detection might be described as follows. Transmitter and receiver are assumed to have a store containing all possible messages. On receipt of a signal contaminated by noise, the receiver compares (correlates) the received information with its store of possible messages and accepts that message which exhibits the highest correlation as the one that was most likely transmitted. The output datum is then the (nonredundant) one number identifying the maximum-likelihood message.

This concept is excellent, provided we can conceive in advance all possible outcomes of the proposed experiment. However, there is great danger that we may render ourselves incapable of recognizing surprise information that would have been of much greater value than any of the messages (experimental results) we might have predicted. This was exactly true in the radiation experiments in the early Explorer satellites. Only expected radiation levels were accounted for in the design of counters and data channels. Consequently, when the satellite encountered much higher radiation intensities, the counter mechanism was completely blocked and an incorrect indication of zero radiation was transmitted. The correct interpretation of these data took a lot of head scratching and several more satellites with more sophisticated and wider range counters to provide the right answer. The lesson to be learned from this example is that we must include in our correlation detectors, and in any other advanced data reduction devices, the ability to recognize that *none* of the *a priori* (expected) results is true. This would take the form of a confidence indication which would add information relative to the actual degree of correlation achieved by the reported maximum-likelihood message.

An added degree of sophistication might be achieved by automatic data handling equipment which recognizes experimental results and continuously adjusts the parameters of the detection process for best results in a changing situation. The storage of voltages, representing present frequency and rate-of-change of frequency, on capacitors in a third-order phase-locked loop, is a simple example of this degree of sophistication. The effect of certain types of automatic gain control or narrow band limiting on noise bandwidth is another example of such adaptive performance, utilizing *a posteriori* data.

It is apparent that any nonredundant datum must be transmitted without distortion or the meaning will be irretrievably lost. This fact has led to intensive effort in the development of error-correcting codes for the transmission of digital data. Such codes actually amount to adding redundancy for the purpose of transmission reliability. Spectrum expansion by pulse-code modulation or frequency modulation is also a means for adding redundancy to improve the reliability of the radio link.

Since the radio link may require redundancy for satisfactory operation, it appears feasible to provide some or all of the required redundancy in the data to be transmitted. In operation, this concept involves averaging of radio noise as well as transducer noise in the final data reduction process.

Statistics; Identification of Signal and Noise

In any filtering or data reduction problem, we are forced to state in advance those characteristics by which we will identify the signal components among the signal and noise information actually received. These *a priori* characteristics can usually be stated only in a statistical sense, and the most common analyses are based on stationary (nonchanging) statistics.

We often have a nice intuitive feeling that "signal" must be that portion of received information that best fits some smooth mathematical function and "noise" must be that part that seems to be random and rapidly changing. Indeed, this is the basis for the very earliest treatment of experimental errors by "least-squares" curve fitting techniques. The work of Norbert Wiener has extended this concept to include completely statistical representations of both signal and noise. His work has allowed the construction of least-square optimum filters for real-time data analysis. These Wiener filter techniques are well known and can be applied to any problem, the object of which is to recover the actual signal waveform in real time. Please note, however, that we can do somewhat better by "post flight" data reduction in which "past" as well as "future" data can be used and finite integrals are permitted. Similar results can be obtained in almost real time if time delay is permitted and appropriate storage mechanisms are included.

The proper application of such statistical filtering techniques for the recovery of actual signal waveforms should play an important part in any study of data processing techniques. However, truly significant gains in data analysis will be accomplished only if further reduction of redundancy is accomplished. This might take the form of the computation of values for the various statistical measures which can be used to describe the signal. Such statistical measures might supplement or replace maximum-likelihood estimates derived from correlation operations.

The previous discussion assumed only random errors which could be recognized by their statistical differences from the signal. In the investigation of advanced data detection, we must consider systematic errors which are statistically identical to the signal. Such errors cannot be eliminated by the processes described previously; however, some types of systematic errors may be corrected by appropriate calibration or by appropriate interpretation based on other data sources. For example, the drift of a strain gauge may be a predictable function of temperature so that corrections can be made to the data, provided only that we have an independent measure of temperature. In current practice, such manipulations occur only at the end of the analysis process and need not be considered in the design of equipment, only in the design of the experiment (*i.e.*, we must remember to include the temperature gauge).

The potential for later correction of such systematic errors may be lost by the manipulations of advanced data detection devices. Consequently, we must be aware of such potential and be prepared to analyze the transformation of systematic errors by the planned manipulations. If the transformation is such that these errors can no longer be compensated, even though they were (in principle) in the original form, we will have to include appropriate functions in the equipment to perform corrections prior to interfering manipulations.

Most easily applicable analyses in information theory assume stationary statistics. This means, in general, that we must predict the actual nature of signal and noise, including relative power levels, during the experiment. That such signal and noise levels are not constant throughout a typical experiment is immediately apparent when one looks at any telemetering record from a missile test.

In order to account for nonstationary statistics in practical data detection equipment, we may be able to include some adaptive features such as variable bandwidth based on signal-to-noise ratio. Such an approach is applicable if the statistics of signal and noise vary slowly relative to the smoothing time of the filter in use. If, however, we are after the greatest possible improvement and are attempting to consolidate data from long time intervals during which statistics change radically, we will be forced to utilize more complete analyses. Such analyses are available in the literature, but practical embodiments in equipment have yet to be demonstrated, although the equations involved can often be programmed for digital computation.

System Optimization

The foregoing technical discussion demonstrates that we have at hand the concepts and analyses required to effectively retrieve any experimental data which can be defined as available, based on fundamental physical limits of detectability. We must recognize, however, that it may not be economically feasible to recover all such data.

In the disciplines of information theory, optimum detection is taken to be that which results in a minimum output-error content (residual noise-plus-signal distortion). In the current context, we assume that certain output data and certain allowable errors are already defined. Then optimum filter and data reduction analysis will be applied to define the detectability of the desired data based on the input signal and noise. Having demonstrated basic detectability, the system optimization takes the form of minimization of the economic penalty (dollars) for the desired increase in informational entropy.

The first phase is the application of ingenuity to conceive and produce reliable and simple equipment mechanizing the required data handling functions. This equipment should be tested to demonstrate proper operation in confirmation of the appropriate theories.

The final decision remaining at this point would be: how much of the required data detection equipment should be designed for airborne environments and used prior to transmission of data on a radio link? This analysis is illustrated in Fig. 2.

The curves in Fig. 2 represent schematically the cost factors relative to the proportioning of the experiment. Each curve shows cost levels corresponding to possible choices for the placement x_0 of the data link. The cost of data transmission is a function of the given vehicle and

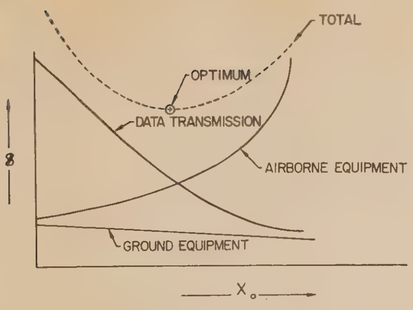

Fig. 2—Cost analysis.

its mission. Some value can be assigned in terms of dollars for each bit of data, redundant or otherwise, that is transmitted to the receiving station. The example shown implies that the available data link is capable of transmitting the entire output of the gauge. As the position of the data link is moved along the data reduction chain, the data to be transmitted are reduced and the corresponding costs are similarly reduced.

Conversely, the costs of placing the necessary data detection equipment in the vehicle environment increase, often quite rapidly. In the example shown, the vehicle does not have sufficient payload capacity to handle all the data reduction functions, and the airborne equipment costs increase asymptotically. Similar asymptotic behavior is possible for data link costs if the vehicle payload is insufficient to permit a transmitter of adequate capacity to handle the entire gauge output.

Ground-based data reduction equipment costs are usually small in comparison to airborne equipment costs which must include, in addition to development and packaging costs, a stiff tariff for the delivery of a payload pound on target (vicinity of Mars, for instance, currently 100,000 to 500,000 dollars per pound).

The sum of all the cost factors is usually a curve which displays a minimum for some choice of data link placement. The exact position of the minimum may vary considerably depending on individual judgment in assigning cost values to the various factors and the final choice of placement of the data link will usually be governed finally by the availability of specific equipments. However, an attempt at such an analysis is deemed worthwhile, if only to gain some evaluation of the potential cost of the desired data. It may even be decided that the data are not worth the economic penalty.

Analyses of the type just described are the province of the operations research specialist, but the concepts and relative values involved are of definite interest in the design of experiments. The operations research analyst would continue the process to define completely the values of each of the proposed space experiments and the relative importance of proposed new vehicle developments. (It may be better to fire more of our currently available rockets than to develop new large rockets for certain tasks.) Such an extension of the analysis is obviously beyond the scope of this paper.

Extraterrestrial Noise as a Factor in Space Communications[*]

ALEX G. SMITH[†]

Summary—**Present-day refinements in communication systems make it appear that extraterrestrial noise sources may establish a fundamental limitation on long-range communications. The various cosmic and solar system radio sources are considered with respect to their intensities, spectral distributions, and temporal characteristics. The most severe forms of interference occur in the long-wavelength regions of the radio-frequency spectrum, so that the future of space communications probably lies in the perfecting of low-noise microwave systems.**

INTRODUCTION

KARL Jansky first detected the cosmic radio noise in 1932 in the course of an experimental study of terrestrial sources of interference. Even after Jansky's discovery, cosmic noise was largely ignored by engineers as being of insufficient intensity to be of practical importance. Now, however, three decades later, improvements in communication systems have reached the point where extraterrestrial noise threatens to impose a fundamental limitation on man's ability to communicate over wide regions of the radio-frequency spec-

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[*] Original manuscript received by the IRE, December 23, 1959.
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trum. This is particularly true when one considers the problem of communication with a vehicle in the "quiet" of space.

The original cosmic noise discovered by Jansky is now firmly established as coming from a broad, diffuse region enveloping the galaxy, or Milky Way. Hundreds or thousands of small, discrete sources known as "radio stars" are superimposed on this background to contribute additional noise. The diffuse hydrogen gas which permeates vast regions of space is a radiator of microwave signals. The sun and the planet Jupiter are known to be powerful, erratic sources of radio-frequency energy, and at least two other planets may also be in this category. Even a comet has been reported as a source of radio noise. It is the purpose of the present paper to consider briefly the probable importance of each of these sources as a factor in space communications.

GALACTIC NOISE

The radio noise from the galaxy is the most widely distributed of the various extraterrestrial sources of interference. It appears to be present in some degree in all directions, but is of course most intense near the plane of the galaxy, especially in the direction of the galactic center in the constellation Sagittarius. Galactic noise has been mapped by various observers at frequencies ranging from less than one mc to 1360 mc, and the most reliable of these surveys have recently been summarized by Ko [1]. A galactic noise map in convenient slide-rule form has been prepared by Menzel [2].

Of particular interest in space communications is the level of galactic noise along the ecliptic. The majority of the more distant space missions will presumably occur in or near the plane of the ecliptic, and it is therefore the ecliptic noise level which will be present as an interfering background.

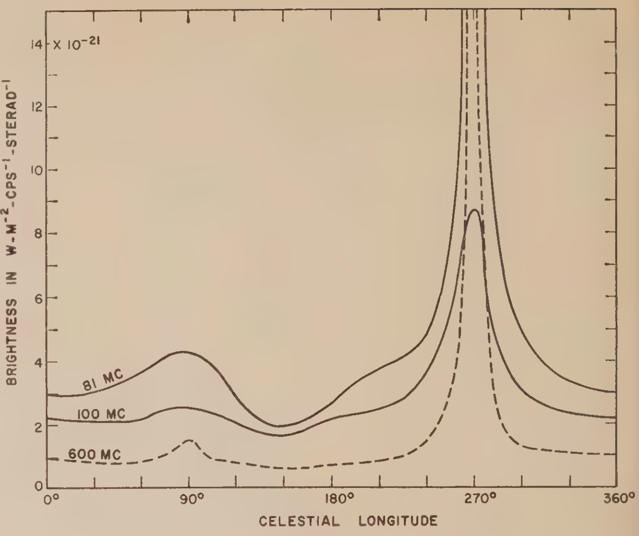


Fig. 1—Galactic noise along the ecliptic at three frequencies. The 600-mc peak extends to a height of 21 units and the 81-mc peak to 27 units.

In Fig. 1 are shown curves of the ecliptic noise level for three different frequencies. The 81-mc data are from the survey of Baldwin [3], the 100-mc data are from the map of Bolton and Westfold [4], and the 600-mc curve is based on the work of Piddington and Trent [5]. The horizontal coordinate is celestial longitude, which is measured in degrees eastward along the ecliptic from the vernal equinox. The ordinate is in units of "brightness" B, where B is the flux density in watts per square meter per cps of bandwidth which would be received at the earth's surface by an antenna having a unit beamwidth of one steradian (it is assumed, of course, that B remains constant over the entire beamwidth). It has been recent practice to plot galactic noise maps in units of "brightness temperature" T, where T is the temperature in degrees Kelvin of an ideal blackbody surface which would have the same brightness as the given area of the sky. Fig. 1 has been plotted in terms of B to permit more direct comparison with the units employed in later sections. Both B and T are units which are appropriate for extended sources—that is, sources which are large relative to the beamwidth of the antenna—and they are related through the Rayleigh-Jeans approximation to Planck's Law,

$$B = \frac{2kT}{\lambda^2},$$

where k is the Boltzmann constant, 1.38×10^{-23} joules per degree K, and λ is the wavelength in meters.

It will be noted from Fig. 1 that at least within the given frequency range the galactic noise along the ecliptic varies only moderately (perhaps ±40 per cent) for some 300° of celestial longitude. In the remaining 60°, the ecliptic, by an unfortunate chance, passes quite close to the galactic center. Here the noise peaks abruptly, reaching, according to the surveys, values from 5 to 20 times the average level of the rest of the ecliptic. It should be remarked that the peak values are subject to considerable error because of the "smoothing" which results from attempting to resolve this sharp peak with antennas of appreciable beamwidth. In particular, the 100-mc peak is probably too low because the antenna used in the original survey had a beamwidth of 17°. By the same token, of course, if relatively low-gain antennas are employed in communications systems, the apparent galactic peak will be reduced in height but extended in longitude. Fig. 2 is an average of numerous scans through the galactic center with a 22-mc antenna at the University of Florida radio observatory. This antenna has a half-power beamwidth in the east-west direction of about 30°, and it will be seen that the galactic peak is spread over approximately 135°.

Fig. 1 indicates that the average galactic level falls with increasing frequency. The exact spectrum of the galactic noise is still in doubt because of the incompleteness of the available surveys and the uncertainties of

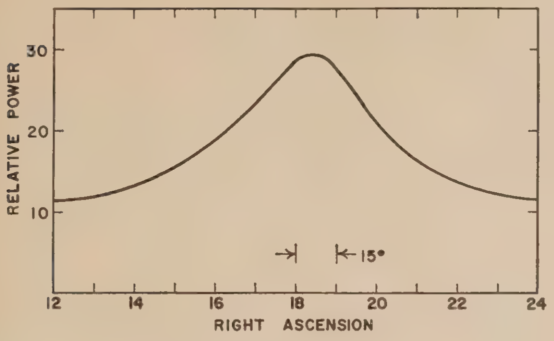


Fig. 2—22-mc galactic noise recorded in early 1959 at the University of Florida with a wide-beam antenna directed at the meridian.

ionospheric absorption at the lower frequencies. Several investigators [6] have come to the conclusion that the spectrum is of the form

$$B \propto \lambda^n,$$

where n is between 2 and 2.7 over most of the radio-frequency spectrum.

Since the galactic noise decreases with frequency while receiver noise generally increases with frequency, it is clear that it is at the lower frequencies that the noise level is apt to be established by cosmic interference. With ordinary types of receivers, the cross-over point typically occurs around 150 to 200 mc. Experience at the University of Florida radio observatory, with antenna beams ranging from 20° to 35° in width, shows that in the 18- to 30-mc region, the noise level of the best commercial communications receivers is virtually negligible compared to the galactic level at any point along the ecliptic.

It is well known that radio astronomers have detected an essentially monochromatic spectrum line due to the radiation of atomic hydrogen at a wavelength of 21 cm (this is the only noncontinuous radiation thus far confirmed). The hydrogen radiation follows a distribution in the sky roughly similar to that of the galactic noise, and reaches a maximum brightness of about 6×10^{-20} watt meter^{-2} (cps)$^{-1}$ sterad^{-1}, well in excess of the galactic brightness at that frequency. Because the hydrogen radiation is limited to a single wavelength, however, it is unimportant as a source of interference.

It naturally follows that as receivers are improved, and, in particular, as such innovations as the maser become practicable for communications, galactic noise will become a dominant factor over still wider regions of the spectrum, extending into the microwave region.

RADIO STARS

Superimposed on the general background radiation due to the galaxy are numerous localized or discrete sources, generally less than 1° in extent. A list of 1936 such sources has been published by Shakeshaft, Ryle, Baldwin, Elsmore, and Thomson [7]. Since the majority of these sources cannot be identified with visible objects, they are known as "radio stars." The strongest of these sources show a tendency to occur near the plane of the galaxy.

The most intense radio star is an object known as "Cassiopeia A." At a frequency of 20 mc this source produces a flux-density at the earth's surface of 5×10^{-22} watt per square meter per cps of bandwidth [8]. (Note that in dealing with sources which are small relative to the antenna beamwidth, it is appropriate to use the concept of flux-density S rather than brightness B. The units are similar, except that S does not involve the solid angle of the beam.) At higher frequencies, the flux-density of Cassiopeia A falls off, reaching a value around 6×10^{-24} watt meter^{-2} (cps)$^{-1}$ at 10,000 mc. Most of the other strong sources show similar spectral behavior.

It is of interest to inquire to what extent such a discrete source will contribute to the received noise in a typical situation. If one assumes a frequency of 100 mc, the flux-density from Cassiopeia A is 2×10^{-22} watt meter^{-2} (cps)$^{-1}$ and the galactic brightness at the position of the radio star is 3×10^{-21} watt meter^{-2} (cps)$^{-1}$ sterad^{-1}. An antenna having an effective area A of 100 meters^2 will receive 2×10^{-20} watt (cps)$^{-1}$ from Cassiopeia A. The beam of the antenna will have a solid angle β of about 0.1 steradian ($\beta = A/\lambda^2$), and it will therefore receive 3×10^{-20} watt (cps)$^{-1}$ from the galaxy. While the contribution of the radio star is appreciable, the discrete source is of secondary importance even in this relatively favorable case of the strongest radio star and a rather weak galactic region.

The next most intense radio star is only about half as strong as Cassiopeia A, and of the remaining sources only 4 reach an intensity of 10^{-23} watt meter^{-2} (cps)$^{-1}$. In general, the noise contribution from the radio stars is minor relative to the galactic background unless extremely high-gain, narrow-beam antennas are involved.

SOLAR RADIATION

The radio-frequency spectrum of the sun is characterized by complexity and variability. Fig. 3 is an attempt (perhaps oversimplified) to indicate the principal features of the radiation, which is often arbitrarily divided into radiation from the "quiet sun" and radiation from the "disturbed sun."

At optical and millimeter wavelengths, the radiation follows closely that expected from a blackbody at 6000°K. At longer wavelengths, however, the radiation from the quiet sun is many times more intense than would be expected from a body at that temperature. In addition, beginning at centimeter wavelengths, time-dependent increases in the radiation become conspicuous. In the region between 2 cm and 60 cm, enhancement of the general radiation over a range of about 2:1 occurs, with a periodicity of weeks or months which is

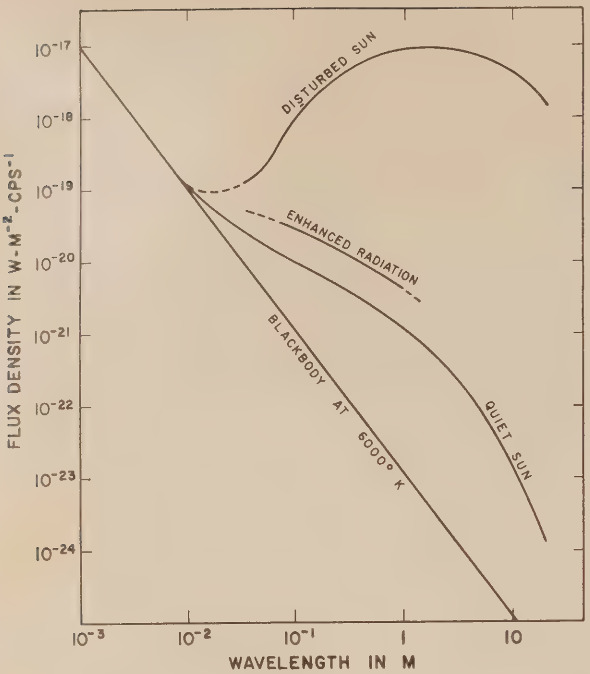


Fig. 3—Chart of representative solar noise levels, with a 6000°K blackbody curve included for comparison. The curve for the disturbed sun represents maximum probable values, but not record maxima.

associated with the area occupied by sunspots. Moderately strong outbursts of radiation in this region, lasting a few minutes, are connected with solar flares.

In the longer-wavelength region of the spectrum, beyond a meter, the general radiation level remains constant for a considerable fraction of the time, but violent disturbances are common, especially near the maximum of the sunspot cycle. So-called "noise storms," consisting of trains of bursts together with a general enhancement of the radiation, last for hours or days and show strong circular polarization. "Outbursts," lasting for a number of minutes, are associated with solar flares; they may reach intensities of millions of times the level of the quiet sun, and encompass virtually the entire radio spectrum. "Isolated bursts" of 5 or 10 seconds duration are even more frequent.

Because of the complexity of the solar radio spectrum, it is difficult to establish statistics on the percentage of the time the sun is "disturbed" at any given frequency. Certainly the disturbances are more frequent and more intense near sunspot maximum. In general, the observed level will lie between the "quiet sun" and "disturbed sun" curves of Fig. 3, although the upper curve illustrates only typical maximum intensities. At least one outburst in excess of 10^{-15} watt meter^{-2} (cps)$^{-1}$ has been recorded [9].

The sun must be ranked as second only to the galaxy as a source of interference, and it takes this secondary position only because it is a localized, rather than a distributed, source, and as such is susceptible to at least partial elimination by directional antennas. It seems certain to create severe problems in the cases of vehicles sent into its own vicinity. The planet Mercury, as seen from the earth, is never more than 28° from the sun; while the earth, as viewed from a vehicle near the orbit of Jupiter, would always be within 11° of the sun.

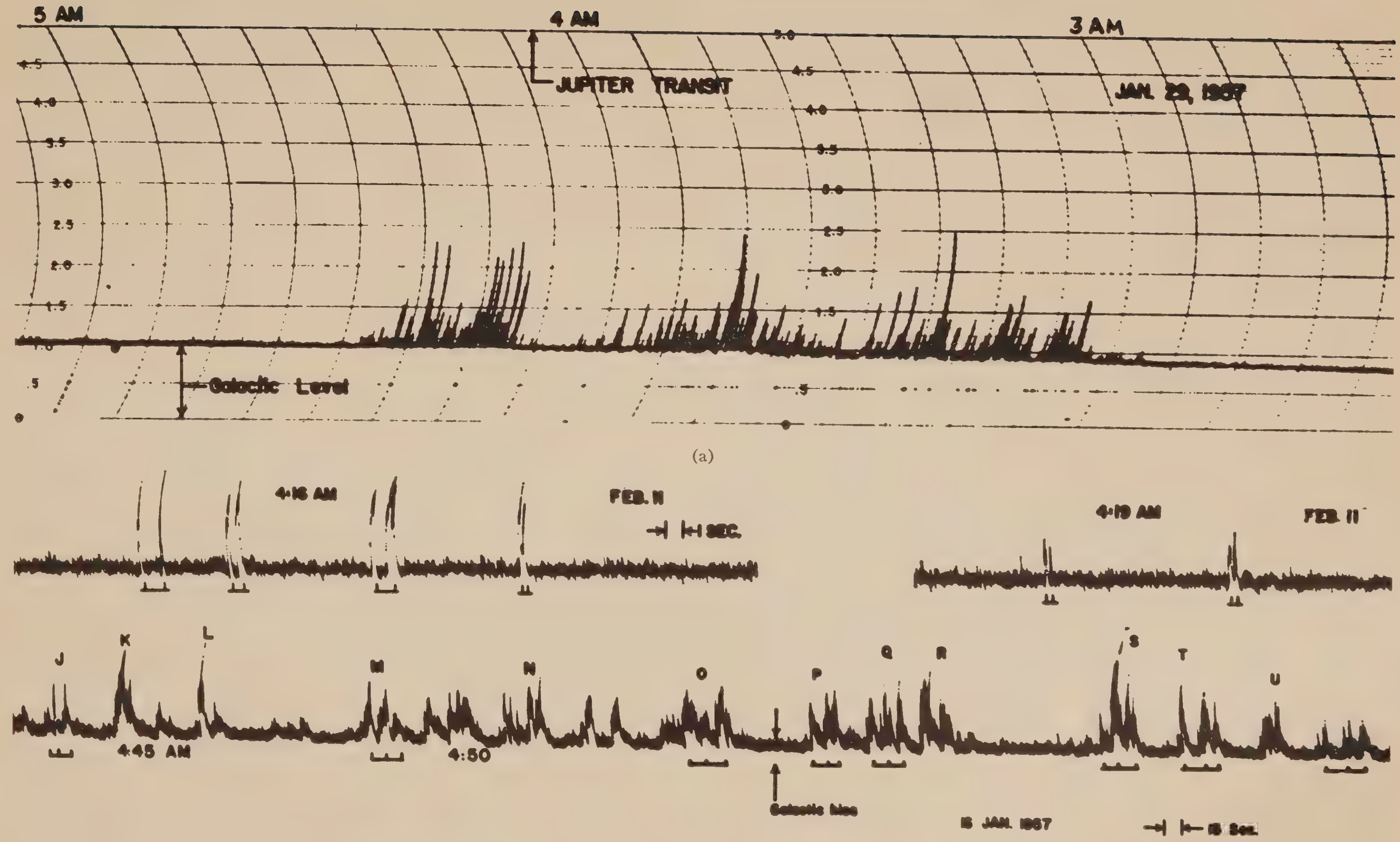
Planetary Radiation

In 1955, B. Burke and K. L. Franklin, while making a cosmic noise survey at 22 mc, unexpectedly discovered that the planet Jupiter is a strong, sporadic radio source. Subsequent investigations by several observatories have indicated that Jovian outbursts may have durations ranging from a few seconds to several hours. A low-speed pen record of a typical noise storm lasting about $1\frac{1}{2}$ hours is shown in Fig. 4(a) (next page), while Fig. 4(b) shows high-speed records of the details of the Jupiter noise. These recordings were made at a frequency of 18 mc at the University of Florida radio observatory.

It will be noted that the noise occurs in bursts or groups of bursts, lasting from a fraction of a second to several seconds, with some indication of doublet or triplet patterns. The stronger bursts observed at the University of Florida at 18 mc have gone off-scale at flux-densities greater than 5×10^{-20} watt meter^{-2} (cps)$^{-1}$ while Gardner and Shain [10] have reported a peak intensity of 10^{-19} watt meter^{-2} (cps)$^{-1}$ at 19.6 mc. The observations of all workers indicate much lower flux-densities at 22 mc and 27 mc; and a search with sensitive equipment [11] has indicated that any sporadic Jovian flux present at 38 mc or 81.5 mc must be below levels of 1×10^{-24} and 3×10^{-26} watt meter^{-2} (cps)$^{-1}$, respectively. Gardner and Shain report a somewhat lower intensity at 14 mc than at 19.6 mc, but the effect of the terrestrial ionosphere at this frequency is uncertain. It thus appears that the observable sporadic Jovian spectrum lies between the terrestrial ionospheric cutoff frequency and a frequency of perhaps 30 mc.

While the Jupiter radiation is highly intermittent, statistical studies show a high degree of correlation of the outbursts with the rotational period of the planet, indicating the existence of localized sources [12]. Since these sources appear to radiate over considerably less than one-half rotation of the planet, a directional effect is involved, which several workers have attributed to a Jovian ionosphere. According to this interpretation, typical values for the critical frequency of the planet's ionosphere range from 9 to 20 mc [12].

Individual bursts appear to have a spectral width of several tenths of a megacycle, and to be circularly or elliptically polarized in the right-hand sense [13]. This polarization suggests the presence of a magnetic field, and T. D. Carr of this laboratory has used the ionospheric model mentioned above to estimate the strength of the field as 7 gauss.



(a)

(b)

Fig. 4—University of Florida records of typical Jupiter noise outbursts. The recording speed in (a) is 6 inches per hour; that in (b) is 5 mm per second. The planet takes over 2 hours to travel between the half-power points of the antenna beam, so that the starting and stopping of the radiation in (a) are actual Jovian phenomena.

Since Jupiter is second in intensity only to the sun as a localized source of interference, the frequency of occurrence of the noise is of considerable interest. Table I is a summary of the reports of several observatories of the percentage of actual observing time during which Jupiter noise was recorded. It will be seen that the 18-mc activity, *e.g.*, ranges from a high of 22 per cent to a low of 1.5 per cent. The University of Florida records indicate that, considering *both* duration and intensity, Jupiter was about 7 times as active in 1956–1957 as it has been in the subsequent two years. Whether these variations can be correlated with other phenomena, such as the sunspot cycle, remains to be established. In a number of instances during the 1957–1958 apparition, short bursts of noise were observed at the University of Florida immediately prior to sunrise, during periods when the planet seemed to be inactive. Carr has hypothesized that these events may be due to transitory focusing of low-level Jovian radiation by a terrestrial ionosphere gradient [13], in which case it may be that the planet emits weakly much or all of the time.

TABLE I

PERCENTAGE OF OBSERVING TIME DURING WHICH JUPITER RADIATION WAS DETECTED, 1955 TO 1959

Source of Data	Year	Frequency	Percentage of Time Jupiter Active
Gardner and Shain [10]	1955–56	19.6 mc	5 per cent
Gallet [22]	1956	18	8.5
Gallet	1956	20	16.9
University of Florida	1956–57	18	22
Gallet	1957	18	6.1
Gallet	1957	20	10.6
University of Florida	1957–58	18	1.5
University of Florida	1957–58	22.2	0.8
University of Florida	1957–58	27.6	0
University of Florida	1959	18	4
University of Florida	1959	22.2	1.5
University of Florida	1959	27.6	0.1

Extensive monitoring of Saturn at 18 and 22 mc by the University of Florida observatory has resulted in the recording of several disturbances of possible Saturnian origin during the 1957 and 1958 apparitions. These events resembled weak bursts of Jupiter noise, lasting only a few minutes and reaching a maximum intensity of 6×10^{-21} watt meter^{-2} (cps)$^{-1}$. Allowing for the greater distance of Saturn, these bursts are comparable to the stronger Jovian outbursts. Smith at Yale [14] has also recorded possible Saturn noises at similar frequencies. At the present time, the low altitude of Saturn as seen from the United States, as well as its location in the noise peak near the galactic center (Figs. 1 and 2), impose observational difficulties which have prevented the results from being conclusive.

In 1956, Kraus reported bursts from Venus which reached an intensity of 9×10^{-22} watt meter^{-2} (cps)$^{-1}$ on 26.7 mc. The bursts consisted of short pulses of much less than a second's duration, and of longer pulses which lasted up to several seconds and had a spectral width of at least 2 mc [15]. Several months of monitoring Venus at 27.6 mc at the University of Florida observatory in 1958 failed to recover the radiation [13]. It is possible that the Venusian activity observed by Kraus has suffered a temporal decline similar to that of Jupiter.

The prominent Comet Arend-Roland (or 1956h) was reported as a radio source by Kraus [16] and by Coutrez, Hunaerts, and Koeckelenbergh [17]. Coutrez, *et al.* measured a peak flux-density of 8×10^{-23} watt meter^{-2} (cps)$^{-1}$ at 600 mc when the comet was at a distance of 0.7 astronomical unit, while the maximum intensity recorded by Kraus at 27.6 mc was 5×10^{-22} watt meter^{-2} (cps)$^{-1}$. Conspicuous comets are, of course, of such infrequent occurrence as to be relatively unimportant as potential sources of noise.

Radio-frequency thermal radiation has been measured for the moon and for the planets Venus, Mars, Jupiter and Saturn. For the moon, at a frequency of 35 kmc, the received thermal flux density [18] approximates 10^{-21} watt meter^{-2} (cps)$^{-1}$; outside of the microwave region the thermal flux is presumably immeasurably small. Planetary thermal fluxes are similarly detectable only at very short wavelengths. The largest reported is that of Venus [19], 10^{-24} watt meter^{-2} (cps)$^{-1}$ at 9500 mc, while the smallest is a value of 4×10^{-26} for Saturn at 8000 mc [20]. At present, these fluxes are obviously of only minor importance as sources of interference, requiring integration times for their bare detection which would be impracticably long for communication systems.

Quite recently, observers at the National Radio Astronomy Observatory, the California Institute of Technology, and the Naval Research Laboratory have detected anomalously strong microwave radiation from Jupiter at wavelengths ranging from 3 cm to 68 cm [21]. Although the radiation is intense enough to indicate unrealistically high temperatures if it is interpreted as thermal radiation (some of the "temperatures" run as high as 70,000°!), the fluxes are still of the order of only 10^{-25} watt meter^{-2} (cps)$^{-1}$. Drake has suggested that the radiation may be due to a Jovian Van Allen Belt.

CONCLUSION

Table II is an attempt to list maximum values of the interference which may be produced at position of the earth by the various sources discussed above. For the solar system sources, the inverse square law must of course be applied to find the intensities at other points in space.

The galactic noise is the most ubiquitous form of interference, and, except for the case of communications taking place within a small angular substense from the sun, it is probably the most serious. The planet Jupiter is an extremely noisy body which is certain to cause problems with communications systems in its vicinity

TABLE II

APPROXIMATE MAXIMUM INTENSITIES OF VARIOUS SOURCES*

Source	Maximum Observed Intensity	Wavelength Region of Greatest Intensity	Temporal Characteristics
Galactic noise	10^{-19} watt meter^{-2} (cps)$^{-1}$ sterad^{-1}	15 meters	Constant
Hydrogen line	6×10^{-20}	21 cm	Constant
Sun	10^{-15} watt meter^{-2} (cps)$^{-1}$	1–10 meters	Sporadic
Jupiter	10^{-19}	15 meters	Sporadic
Saturn (?)	6×10^{-21}	15 meters (?)	Sporadic
Venus (?)	10^{-21}	10 meters (?)	Sporadic
Moon (thermal)	10^{-21}	*M* meters	Constant
Radio stars	5×10^{-22}	15 meters	Constant
Comet	5×10^{-22}	10 meters	Variable
Planets (thermal)	10^{-24}	*M* meters	Constant

* Data do not extend below 20 mc, since ionospheric absorption introduces serious uncertainties at that point.

(although, by the same token, the Jovian radio outbursts might be used to actuate homing devices). Saturn and Venus may also belong in the category of sporadic radio-frequency emitters, although the evidence in these cases is not as yet clear-cut.

Examination of the spectral characteristics of the various sources indicates that, except for thermal emission, interference is most serious at the long-wavelength end of the radio-frequency spectrum. This would suggest that the future of long-range communication systems lies in the development of low-noise microwave devices such as the traveling-wave tube and the maser. Because of ionospheric absorption, knowledge of the spectra of extraterrestrial sources at frequencies below 20 mc is incomplete and inaccurate. The extension of measurements into this region is one of the exciting possibilities associated with lunar or space observatories.

ACKNOWLEDGMENT

The radio-astronomy program at the University of Florida is supported by the Office of Naval Research, the U. S. Army Office of Ordnance Research, and the National Science Foundation. Prof. T. D. Carr assisted in the collection and reduction of the University of Florida data.

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Space Communications Requirements of the Department of Defense*

JAMES O. SPRIGGS†

Summary—**Military requirements for space communications are described in terms of general needs rather than specific applications. Communications to meet these needs may be divided into communications to, from, and among objects in space. The functions of these communications are command, tracking, and data transmission, the major considerations affecting each function being briefly described.**

Communications by means of objects in space, which is of most interest here, is comprised of systems utilizing either passive or active relay objects. The latter systems may be delayed retransmission types or real time repeaters, both of which may have military application.

THERE is enough uncertainty as to what is meant by a military requirement to suggest that any discussion of the the subject should begin with at least a perfunctory explanation. There are, of course, formal, stated military requirements generated by the Military Departments individually, or jointly through the Joint Chiefs of Staff. In general, these requirements will be in areas where the need for a weapons system or components is clearly defined and the technology that supports it is well advanced. This type of requirement may be carried so far as to attempt to describe the weapons system to meet the need, rather than just the need itself. However, needs or requirements, in the broad sense, can exist without the technology to support them, and technology can exist without the need for its application to a military use. There are, accordingly, areas where the technology to meet the need is new or perhaps does not exist. This latter situation is true for much of space communications, where application of the latest advances in orientation control systems, low-noise receivers, modulation techniques, and efficient converters of power to radio frequencies are required by the great cost of putting payloads into space. These applications will grow and become better defined as a result of the continuous relating of an improved appreciation of these needs and the developing technology.

Space communications is defined as communications with and among objects in space. Communications by means of objects in space may be considered to be an application of the techniques of space communications.

In regard to communications with objects in space, the communications link to the object is often easier to achieve than the link from it, because the information rate required is usually considerably less, since it is limited to a few discrete preselected commands. This is true because the space object is usually the source of information obtained by measuring devices in the object. However, even for those missions where the information rate can be considered high, as in, for instance, the outgoing leg of a television relay satellite, the average power and antenna aperture needed for the work are not so limited by weight considerations, highly directive antennas being practical on the ground. The problems that do exist for the outgoing link still center around the space-borne equipment, involving, in addition to the overwhelming problem of reliability in a difficult environment, resistance to interference and, more specifically, linearity of signal channels.

The incoming leg of a communications link with a space vehicle will be more difficult, primarily becauee the power available for the purpose will be restricted by the very high launching costs per unit weight, and high reliability will be required for high-power components. Antenna aperture will be limited both by the cost and also by considerations of constructing and automatically and reliably orienting such apertures in space. In addition, for some applications, the need for illumination of a large area on the earth rather than the single addressee characteristic of the ground-to-space leg may restrict the antenna directivity and consequently the aperture and gain available.

Communications among objects in space unfortunately has all the problems of ground-to-space and space-to-ground, plus additional difficulties associated with initial and continued orientation of antennas, which are relieved only slightly by the availability of a wider frequency spectrum for the purpose (below the VHF and above the SHF bands). The technical considerations of communications ground-to-space, space-to-space, and space-to-ground have been quite concisely discussed in an article by Rechtin.[1]

Military requirements for communications with objects in space involve the functions of command, tracking and data transmission. It is well to recall here that the purpose of communications is to transmit information and that information consists of change, if change is defined to include more precise determination of a steady-state condition. Accordingly, the purpose of commands is to achieve a change; for example, to change the path of a space vehicle, perhaps to achieve a rendezvous with a previously launched satellite; to direct recovery of a data package at a particular location; to start or stop a data transmitter; and to perform a se-

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* Original manuscript received by the IRE, December 2, 1959.

† Advanced Research Projects Agency, Dept. of Defense, Washington, D. C.

[1] E. Rechtin, "Feasibility of space communications," in "Space Technology," Howard Seiffert, Ed., John Wiley and Sons, Inc., New York, N. Y., ch. 21; 1959.

quence of tasks or experiments that cannot be preprogrammed but may be dependent on earlier data gathered by the space vehicle. Commands are accordingly required for satellite interception, recovery of weather photographs, readout of stored data, and directing the acquisition of particular data that have been found to be of interest.

Tracking of space vehicles consists of measuring range, range rate, angles and angular rates of a space vehicle from an observation point. The space vehicle's path comprises information, or more correctly, what is not already known about its path comprises information. This information is communicated by the change (over what can be predicted) of length and direction of an electromagnetic path.

Tracking of space vehicles for military purposes is a difficult subject to discuss briefly. In general, it may be said that any vehicle must be tracked well enough so that it can be found, unambiguously, at any future date. The accuracy of tracking and, correspondingly, the accuracy of prediction of its path required for this purpose, varies with the time lapse expected before the next observation, and the number of other objects in space and the similarity of their paths. The frequency of observation is largely determined by unpredictable perturbing influences, such as uncertainties in air drag; of course, more frequent observations improve the measurement accuracy. This sets a minimum value for comprehensive knowledge of vehicle paths. For a particular military objective the accuracy required may greatly exceed the minimum, as in navigation, mapping, and geodesy. It may also be less than this so-called minimum, when a comprehensive knowledge of all space objects for a particular mission is of no consequence. An example of this is the delayed repeater communications satellite, where at remote locations the satellite's orbit need only be known well enough to acquire it in a moderately broad beam on the next usable orbital pass.

Data transmission from military space vehicles will be similar to that for nonmilitary use with regard to the variation in need for amounts of information to be transmitted. Most missions will require relatively low amounts and rates of transmission. Others, such as meteorology, are limited by the information storage capacity and, more basically, by the power that can be provided in the space vehicle. Differences between the military missions and the nonmilitary are characterized for the military by an additional need for security, both in the characteristics of the data sent and in its availability for readout, and by added resistance to interference.

Communication by means of space vehicles has important potentialities to meet military needs. Stated broadly, communication beyond line-of-sight but using what were formerly considered "line-of-sight" frequencies has rapidly become possible by artificially induced means. Long distance point-to-point communications become limited by the power that can be produced in (or reflected from) a satellite, rather than being limited by the usable bandwidth that is available in the HF and lower spectrums or the severe signal attenuations inherent in natural tropospheric and ionospheric scatter circuits.

Two approaches to communications by space vehicles are possible: the use of either active or passive space objects as relay points. These objects may utilize frequencies from 20 mc to above 50 kmc and, in theory, optical frequencies corresponding to the atmospheric "windows."

Passive space relays are attractive by reason of their simplicity, reliability and lack of intermodulation problems. They are unattractive because of their intimate relationship to the "fourth power" law that makes the received power a function of the fourth power of the distance from the transmitter to the space object to the receiver. Distances in space are inconveniently large for this purpose. Passive objects may be metallic balloons, dipoles, assorted configurations of flat surfaces, and miscellaneous debris such as burnt-out final stages of launching vehicles and nonradiating satellites.

Active space objects for communications are perhaps of more military interest than the passive objects, if the reliability problems can be solved. These active types can be divided into two categories, delayed relay and real time relay. In the first type, information via a ground-to-space link is stored in a satellite flying at a relatively low altitude, physically transported to a new location, and the stored information is read out at this location. The well-known example of this technique is the SCORE Project. This type has the advantages of short terminal transmission paths (a few hundred miles), low demands on the launching vehicle's performance or, conversely, higher potential power in the space equipment and consequently a higher data transmission rate. It has the disadvantages of an appreciable time delay due to the satellite travel time plus additional delays because of synchronization incompatibility. These latter delays are a function of the orbit period and the earth's rotation period for particular inclinations of orbit and site locations. For military purposes there are some possible advantages in this type from a security point of view, because of the limited areas from which a low-flying satellite may be seen.

Low flying satellites do not necessarily have to use this relay technique. An interesting possibility is to use a number of satellites with a prescribed orbital phase relationship to each other whereby, in cooperation with a corresponding series of ground stations, a multiple hop HF communications system in real time may be simulated at VHF and UHF.

A more intellectually satisfying approach is that of the single vehicle real time repeater. In order to be seen from widely separated distances on earth a single vehicle must, of course, be at a high altitude. This criterion is met at about 8000 miles altitude. However, the energy required to impart this circular orbit altitude corresponds to that required to escape from the earth's gravitational field and, in addition, requires a number of satellites in a pattern to provide continuous point-to-point communications. A satellite at about 19,000 nautical miles altitude, variously called a 24-Hour, Stationary or Synchronous Satellite, becomes interesting because only one satellite is required for continuous, point-to-point (or point-to-area) communications for nearly a hemisphere of the earth's surface. However, this requires considerably more energy for injection than even an escape mission requires, so that for a given vehicle a lesser payload is possible than for satellites at lower orbits. At the same time the power requirements have gone up in proportion to the square of the additional distance or, more realistically, the bandwidth that can be transmitted has been reduced in proportion to the square of the distance.

These considerations must be balanced against each other and against many others in any selection of a space communications system to meet military needs. The low-flying delayed relay satellites appear to have promise of handling a great amount of the routine communications traffic associated with logistics and personnel operations where moderate time delays are not important and may actually be less than that due to normal HF traffic backlogging. This will relieve the HF circuits for greater reliability in higher priority messages. The higher altitude satellites can be used to provide reliable real time communications where the bandwidth requirements are compatible. As launching vehicle efficiencies improve, in terms of pounds of payload in orbit per dollar, and as reliability and useful life problems are solved, satellites will become increasingly important for military communications.

Communication Satellites*

DONALD L. JACOBY†

Summary—**This paper is intended to provide a review of communication satellites starting with their comparatively brief history and continuing through present developments and future concepts and the probable impact on global communications.**

The advantages and disadvantages are considered for various types of passive and active devices, for various orbits, and from the standpoint of both military and commercial applications. Consideration of all major technical and economic factors leads to the conclusion that a system of 3 or 4 repeater satellites in 24-hour orbits will best meet future world-wide communication requirements. A number of system concepts are described, including time-synchronous and frequency-sharing systems.

Important aspects of communication satellite design are discussed including electronics, antennas, power supply, structure, attitude and position stabilization, command control, and telemetering. Selection of frequency is shown to be not critical over a wide range. Choice of design parameters such as power output, antenna gain, stabilization accuracy, etc., is largely dependent on the desired capacity of the communication system and the available satellite payload. Some typical parameters for a high capacity system are presented.

Reliability is an over-riding consideration in satellite design and it is proposed to achieve desired life by proper choice of components, by use of redundancy, and by minimization of satellite requirements at the expense of the ground equipment.

Based on published information on ARPA-NASA programs and booster capabilities, some estimates are made of the rate of progress which can be expected in communication satellites, leading to their eventual use in military and commercial communications. Wide application is foreseen because of increasing communication requirements which will saturate existing facilities.

INTRODUCTION

THE next ten years will see a revolution in world-wide communications with the advent of the communication satellite. In this age of jet planes, nuclear power, and moon rockets, our communication facilities have simply become outmoded. These facilities have served us well and will continue to do so in the future, but they are not good enough. They will not handle the greatly increased volume of communications. They will not support world-wide television which could contribute to improving international understanding. Present communications are too easily disrupted. A slight increase in sunspot activity can cause all radio communication to Europe to be blacked out. A fishing trawler may accidentally cut the North Atlantic telephone cable. While these events present difficult problems to civilian communications, the implications of even temporarily being cut off from the rest of the world are far more serious from a military standpoint.

During the past two years, communication satellites have attracted considerable interest within both industry and government. There has been a successful launching of a communications satellite (Project SCORE), and development programs have been initiated both within the civilian space agency and the Department of Defense. Rather than discuss any specific programs, an attempt at an underlying philosophy of communication satellites will be presented, starting with the objectives.

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* Original manuscript received by the IRE, December 2, 1959.

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OBJECTIVES

What should be some of our major objectives in developing a system of communication satellites? First of all, we are looking for *reliable* communications which provide uninterrupted service over long periods. The system should have *high capacity* with capability for handling large volumes of all types of traffic. It should be sufficiently *flexible* to serve the maximum number of potential users. There should be *minimum delay* in transmission. Last but not least, it should be *economical* in terms of the cost of the services rendered. Each of these factors will be discussed in more detail, and the communication satellite will be compared with some of our existing facilities.

Reliability

There are two types of reliability of interest to us. The first of these is propagation reliability. The high-frequency band has always been subject to the vagaries of the ionospheric layers which surround the earth. Thus, only a portion of the HF band is actually useable at any given time over a particular path. In addition, multipath effects seriously limit the amount of information which can be transmitted over a given channel. Added to these limitations are the blackouts which may result from ionospheric disturbances caused by sunspot activity. (As indicated in the *New York Times* last March, similar disturbances can be introduced by high-altitude nuclear explosions.) One is forced to the conclusion that HF radio via the ionosphere is not highly satisfactory as a propagation medium.

By contrast, a communication satellite of the active repeater type employing line-of-sight transmission at microwave frequencies would be extremely reliable from a propagation standpoint. However, the communication satellite introduces a different type of reliability problem, that of reliable unattended operation for long periods while in orbit. Some experts doubt that a reliability sufficient to make a communication satellite economically feasible can be achieved. It is believed that a reliable communication satellite can be developed with a minimum guaranteed life of one year based on the following assumptions: there is major effort to develop components of proven reliability for this application; all components are operated well within their ratings; the satellite design provides adequate protection during the launching and while in the space environment; and, finally, adequate use is made of redundancy to further increase the probability of successful operation. Despite the formidable problems, the satellite does enjoy some advantages. Unlike ground equipment, particularly military, which must withstand extremes of operating temperature, humidity, atmospheric pressure, and mechanical shock, the electronic equipment in the satellite will be provided, once in orbit, with an almost fixed environment devoid of the factors that generally contribute to reducing component life.

High Capacity

Through the years we have been dependent, almost exclusively, on high frequencies in the band 5 to 20 megacycles for our long range global communications. These frequencies are shared among all countries and must support both military and civilian applications. The narrow range of frequencies, and the propagation characteristics discussed previously, seriously limit the total communication capacity.

It is not surprising that there is always great interest in new techniques which promise to open additional areas of the frequency spectrum to long-range communications. Recent examples are ionospheric and tropospheric scatter propagation. The communication satellite will open up the complete range of frequencies to 10,000 megacycles for long range communications, thus providing nearly 1000 times the spectrum available in the HF band.

Flexibility

One of the requirements is to provide sufficient flexibility in our system so that new or changing demands around the world can be satisfied without major overhaul or replacement of facilities. A major disadvantage of the submarine cable, for instance, is its lack of flexibility, being strictly a point-to-point fixed-plant type of facility. On the other hand, a system of communication satellites in 24-hour equatorial orbits, by providing wide bandwidths and essentially global coverage, places a minimum of restraint on the number and location of ground stations served and the volume of communication furnished to each.

Minimum Delay

Another of our objectives is to speed up our communications. All too frequently urgent messages are delayed because our facilities are congested or because propagation conditions are poor. Recently, a television program was seen in the United States only a few hours after it was broadcast in England and this was considered a major achievement. Some of the advantages of communication satellites previously discussed, such as the wide bandwidth, will not only make possible world-wide television broadcasting in real-time, but will reduce delays in all types of communications.

Economics

If one accepts the fact that communication satellites will improve global communications, it is still reasonable to ask how much they will cost. Here we find that communication satellites have some unique characteristics. In the first place, the quantity of satellites required is not sufficient to warrant production tooling, and, therefore, they will always be expensive by comparison with mass-produced equipment. Of far greater significance, however, is the cost of the launching vehicles, which may run 5 to 10 million dollars or more depending on the satellite weight and the orbit. The present state of the art requires perhaps three launchings to insure one successful satellite, but missile experts hope that this ratio can be improved in the future. If the most pessimistic figure is taken, it could cost as much as 90 million dollars for the vehicles alone for a system of 3 satellites in 24-hour orbit. Once in orbit, a communication satellite has no operating and maintenance costs in the usual sense. However we must plan on periodically replacing satellites which have failed. It is easy to see that, on a long term basis, the cost of a communication satellite system is thus intimately tied to the reliability of the satellite, and a few million dollars to improve reliability during development would save many times that amount during each year of operation.

Survey of Types of Communication Satellites

Thorough review of all factors has led to the conclusion that an active repeater type of satellite in a 24-hour equatorial orbit offers the most promise for advancing global communications. However, in view of the reliability problems and the anticipated costs of a communication satellite program, it would be well to briefly review the pros and cons of alternative approaches which are under development or have been proposed.

Passive Reflector

A concept which has attracted considerable interest is that of the passive reflector satellite as described recently.[1] Some of the advantages of such a system are its inherent reliability and the possibility of being shared by a large number of users operating over a wide range of frequencies. However, a typical system operating between two locations 2000 miles apart would require a total of 24 100-foot balloons in randomly spaced orbits at 3000 miles altitude for an outage time of 1 per cent. In addition, to support meaningful communication bandwidths, extremely large transmitter powers, low-noise temperature receiving systems, and large tracking antennas with beamwidths of the order of 0.05° are required. Substantially greater numbers of satellites would be required to provide longer range or wider coverage than the examples cited and, therefore, they do not appear to be an economical solution to providing truly global communications.

The passive reflector satellites would be more attractive if they could be stabilized in attitude, permitting use of more efficient reflecting surfaces, or if the satellite orbits could be synchronized so as to reduce the number of satellites required. However, the satellites then cease to be "passive" and reliability is no longer inherent in the system.

Delayed Repeater Satellite

This concept envisons a satellite in low-altitude (300 to 2000 miles) orbit providing communications between a number of ground stations. Each ground station provides facilities for storing communication traffic destined for other stations and transmitting this traffic to the satellite during the time the satellite is in view. Simultaneously, the ground station will receive from the satellite traffic from other ground stations which have been stored in the satellite. The satellite is equipped with recorders and appropriate control circuits which can be commanded from the ground or perhaps operate on a prearranged program.

A satellite in equatorial orbit can provide communications to stations in the equatorial zone on each satellite orbit. In orbits other than equatorial, a satellite will serve a larger area but will in general serve a particular station less frequently. The higher the altitude of the satellite, the longer is the time in view for each ground station and the larger is the area served.

The delayed repeater satellite appears to be an economical method of providing communications where delays of 2 to 3 hours are tolerable. It is most efficient when operating in the region of the equator. It is not intended to provide global coverage or communication of a high priority nature.

Communication Satellite in 24-Hour Orbit —System Design

This concept is illustrated in Fig. 1. Three satellites at an altitude of 22,300 miles and equally spaced over the equator circle the earth in 24-hour equatorial orbit. Because of the earth's rotation, they appear to remain

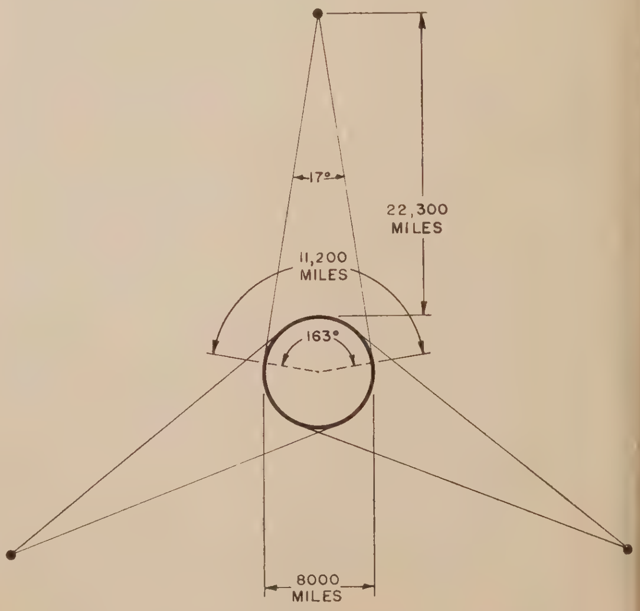

Fig. 1—Concept of three communication satellites in 24-hour equatorial orbit, showing geometrical relationships in the equatorial plane.

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[1] J. R. Pierce and R. Kompfner, "Transoceanic communications by means of satellites," Proc. IRE, vol. 47, pp. 372–380; March, 1959.

fixed to an observer on the earth. Such a satellite system will provide complete global coverage with the exception of the extreme polar areas. Each satellite will be equipped to receive, amplify and retransmit signals originating at stations within its area of coverage and intended for other stations in the same area. Switching between areas could be accomplished by direct relay between satellites, but since this might prove difficult to control, a preferred method is to locate ground repeaters in the areas visible to 2 satellites, as shown in Fig. 2.

Within the concept described there are at least three approaches to system design. In the first of these [see Fig. 3(a)] and the most straightforward, two frequency bands are employed, one for transmissions from satellite to ground and the other for transmission from ground to satellite. These frequency bands are subdivided, not necessarily equally, among the ground stations and the inter-area repeaters.

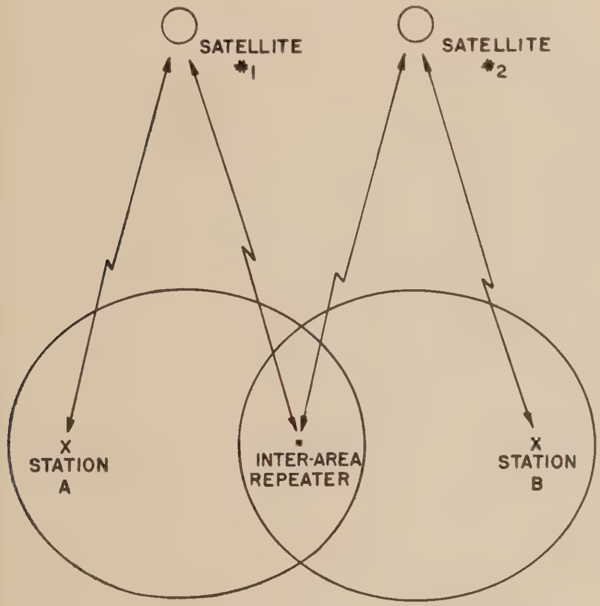
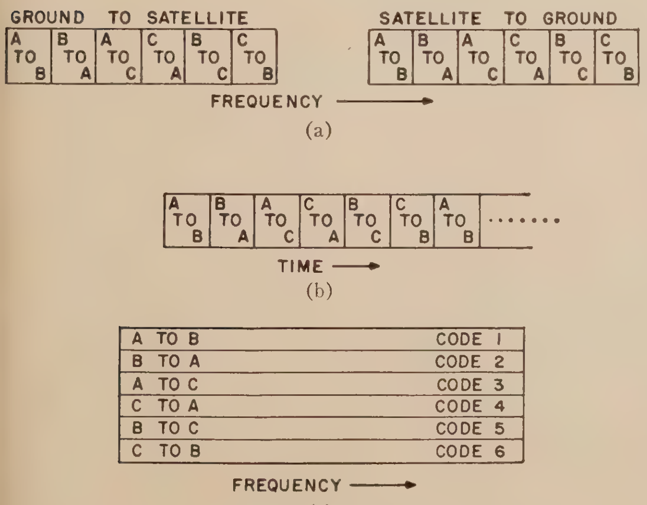


Fig. 2—Method of switching between areas in a 24-hour satellite communication system.



(a)

(b)

(c)

Fig. 3—System design approaches in a 24-hour satellite communication system.

In the second approach [see Fig. 3(b)] all stations would have common frequencies, but would transmit and receive at different times. This system entails greater complexity than the first because of the need for maintaining precise synchronism between stations and the probable variations in delay time in the transmission path due to fluctuations in satellite position.

A third approach would again have all stations sharing common frequencies, but with all stations transmitting and receiving simultaneously. Each signal would be furnished with an identifying code. Separation of signals at receiving stations would be by correlation detection techniques [Fig. 3(c)].

Some discussion of frequencies to be employed for these systems seems appropriate at this point. Frequencies below a few hundred megacycles should be avoided because of ionosphere effects. Frequencies above 10,000 megacycles are subject to attenuation in the atmosphere due to oxygen, water vapor, and rain in varying degrees, the attenuation being most pronounced for grazing paths and less significant for paths normal to the earth's surface. Having established rough upper and lower limits on frequency, the basic formula for transmission in free space will be examined.

$$P_R = P_T + G_T + G_R - 37 - 20 \log f - 20 \log d$$

where

P_T = transmitted power in dbw,
P_R = received power in dbw,
G_T = transmitting antenna gain in db (relation to isotropic),
G_R = receiving antenna gain in db (relation to isotropic),
d = distance in miles,
f = frequency in megacycles.

If we now decide that the satellite antenna should have a fixed beamwidth such that it exactly illuminates the earth, and if we further establish a practical limit on the size of the ground antenna, only one of the antenna gains will be a function of frequency and P_R will then be independent of frequency. Thus, the actual choice of frequency boils down to availability of reliable components, such as tubes having necessary power output, bandwidth, efficiency, and considerations of mutual interference with other users of UHF and SHF frequencies.

Noise is not expected to be a serious problem in the ground-to-satellite path since high-power transmitters may be employed. However, satellite transmitter power may be limited by payload restrictions in which case use of parametric amplifiers or masers may be required to minimize the effective noise temperature of the ground receiver.

Table I lists typical system parameters for a hypothetical communication satellite system handling 12 PCM voice channels between a pair of ground stations.

TABLE I

Frequency	Satellite	Ground
Transmitter Power	2000 megacycles	2000 megacycles
Antenna Gain	18 decibels	49 decibels
Receiver Bandwidth	1 megacycle	1 megacycle
Receiver Noise Figure	10 decibels	3 decibels
Carrier to Noise	37 decibels	24 decibels
Channel S/N		60 decibels

SATELLITE DESIGN

Some aspects of communication satellite design, which are of particular significance if we are to meet our over-all system objectives, will now be briefly discussed. More detailed information is available in a recent paper.[2]

Weight Limitation

For the next few years we will be severely limited in the payload that can be placed in orbit by available boosters. These capabilities can be expected to increase and within 10 years we should be able to place payloads of several thousand pounds into 24-hour orbit. However, it is generally true that the heavier the payload, the greater will be the cost of the booster to place it in a given orbit. Therefore, it is important to design for minimum weight by use of materials and structures with maximum strength-to-weight ratio, by employing the most efficient power sources, and by minimizing power requirements.

Stabilization

Attitude stabilization of the satellite is essential to positive control of the satellite orbit and is also a major factor in weight reduction. It permits use of a directional antenna with consequent reduction in power requirements. It also permits the incorporation of solar cell platforms that rotate to always face the sun, thus improving power supply efficiency by a factor of 6. Attitude stabilization may be achieved by means of sun and star trackers, horizon sensors, or radio signals from the ground, controlling a system of gas nozzles.

Antennas

The satellite antenna may be a single fixed parabola. Linear polarization is satisfactory, provided that the ground antenna is circularly polarized. In the case of a 24-hour satellite, a beamwidth of 20° will illuminate the earth with some margin provided for attitude variations. Higher gain antennas may be employed to illuminate specific areas or increase system margin but this either places more severe requirements on attitude stabilization or requires some form of steerable or electronically scanned antenna.

Power Supply

As discussed previously the most efficient power supply in the foreseeable future is a solar cell platform which rotates so as to always face the sun. Present solar cells have an efficiency of 10 per cent and will provide approximately 10 watts per square foot of platform area. Some improvement in efficiency, perhaps to 13 per cent, is foreseen in the future. A battery supply should be added in parallel with the solar cell supply if operation is desired during periods when the satellite is in the earth's shadow. This amounts to less than 1 per cent of the time for a satellite in 24-hour orbit.

Communication Electronics

The major emphasis in the design of the communication electronics must be on reliability. We must select only components of proven reliability; we must operate them well within their ratings; and components must be protected from damage by micrometeorites and radiation. Present microwave tubes are not capable of operating continuously for a year or more for this application and extensive research and development is required in this area. Reliable components will be supplemented by prudent use of redundancy to insure maximum useful life of the satellite. A likely circuit configuration is shown in Fig. 4. This is basically a heterodyne repeater, with traveling-wave tubes a logical choice for the wide-band amplifier stages.

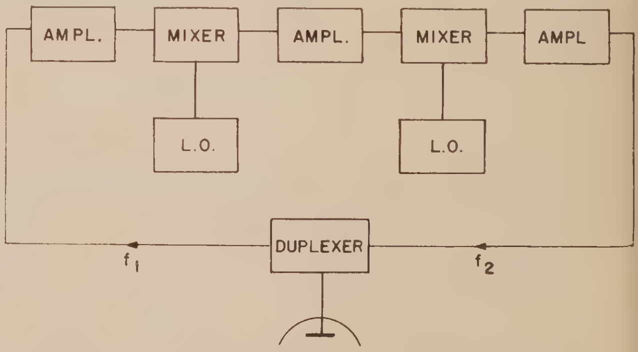


Fig. 4—Basic design of communication satellite repeater.

Command System

The satellite will undoubtedly require some degree of control from the ground through a command link. Such a link could provide control of satellite position as well as commands to activate or deactivate portions of the satellite communications equipment and other functions. Commands would be in coded form to minimize the possibility of interference.

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[2] J. E. Bartow, G. N. Krassner, and R. C. Riehs, "Design considerations for space communication," 1959 IRE NATIONAL CONVENTION RECORD, pt. 8, pp. 154–166.

Telemetry System

There is also a requirement for a telemetry link from the satellite to the ground to provide information vital to operation of the communication satellite system. The telemetry system will monitor the performance of the communication equipment, the power supply, and the attitude stabilization system and will provide acknowledgment of commands and verification that they have been acted upon. During the research and development phase, the telemetry link serves the additional important function of checking the adequacy of the design, the information derived serving as a basis for design modifications in later satellites.

Orbit Correction

Ideally, a satellite in a 24-hour equatorial circular orbit will remain over a fixed point on the earth. In practice it is anticipated that initial inaccuracies together with effects of the moon's gravity, solar radiation pressure, etc., will bring about perturbations in the orbit requiring periodic correction during the useful life of the satellite. In order that the satellite orbit may be properly controlled from the ground, it is likely that a tracking beacon will be incorporated in the satellite. Tracking will be required at a number of ground locations unless the tracking beacon is of a transponder type, supplying range in addition to angle information. Doppler measurements are useless in tracking a 24-hour satellite because of the small magnitude and unpredictable variations of differential velocity. Information from the ground tracking stations will be fed to a computer which will determine the direction and timing of the corrective thrusts which must be applied to the satellite. It appears feasible to maintain a satellite within 1 or 2 degrees of its desired location by these techniques.

The command, telemetry, and tracking systems may operate close to the communication band and share common antennas. However, they do not require wide bandwidths and could operate at considerably lower frequencies. The decision may depend on whether tracking and position control are performed at the communication ground station or at separate locations.

Structure

As discussed previously, there will be a maximum weight for the satellite. There will also be maximum dimensions for the satellite during the launching period as dictated by the final stage rocket configuration. Hardware which will project from the main body of the satellite, such as the solar cell platform and the antenna, will be in a collapsed position during launching, and extended only after separation from the last stage. The satellite must be designed to withstand the conditions of vibration and shock during launching and to have a maximum degree of dynamic stability in orbit.

Thermal Design

The satellite must provide a satisfactory thermal environment for the electronics and other components. The power dissipated in the form of heat by the electronic equipment must be brought to the outer surface whence it can be radiated. The outer surface must be designed, using special coatings as required, to strike a balance between radiation and absorption such as to maintain internal and external temperature within desired tolerances. In the particular case of the solar cells, it is essential that close thermal control be maintained, since their efficiency drops off rapidly at higher temperatures. Thermal storage devices may be required to prevent wide variations in thermal conditions as the satellite traverses its orbit.

Conclusion

Serious shortcomings exist in our present global communication facilities. Communication satellites promise greater capacity, wider coverage, more flexibility, and fewer delays than present transmission systems. The operating cost of communication satellites is intimately tied to the problem of reliability. With sufficient emphasis on the reliability aspects, satellites will assume the prominent role in communications for which they appear destined.

Interference and Channel Allocation Problems Associated with Orbiting Satellite Communication Relays*

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Summary—**The use of active and passive relays is considered for application to long-distance global trunk communication, with particular emphasis on economic utilization of the media from the traffic capacity viewpoint. Active and passive techniques are compared with regard to power requirements, coverage, mutual interference, and ability to exploit wide-band modulation systems to reduce interference. With the emphasis on microwave transmission, narrow beamwidths, and a multiplicity of relays, channel allocations of the future will necessarily be determined by spatial considerations, in addition to specifying frequency bands. Examples with typical global paths and assumed active and passive systems are illustrated. It is concluded that, although a great increase in transmission capacity is forecast with the new techniques, a much broader scope of coordination will be necessary to control interference.**

INTRODUCTION

MILITARY requirements for global communication trunks are continually increasing because of the demands for higher capacity, improved reliability, and greater flexibility imposed by the addition of new weapons systems. The advent of the satellite relay in orbit is agreed by all to be the logical medium to supplant the over-burdened, erratic, and vulnerable ionosphere for long-distance communications. The possibility of line-of-sight relay transmission over thousands of miles offers promise of large transmission bandwidths to be exploited, freedom from violent fading and multipath distortion, and protection from interference by virtue of narrow antenna beamwidths at microwave frequencies.

From past experience, it is known that once a new propagation medium is proven useful, little time passes before the medium is supporting a large volume of traffic. In view of a number of factors associated with satellite communications, it is likely that mutual interference problems may occur early in the history of its development. Some of these factors are listed.

1) The location of trunk terminals for military applications must be well distributed in geography and reasonably mobile, in order to meet the changing traffic demands of the geopolitical and military situation.
2) The frequency spectrum considered most suitable for this type of application (about 2000 to 10,000 mc) is already in general usage by ground and airborne radar systems and conventional radio relay.
3) Communication, tracking, and telemetering systems for space vehicles are likely to occupy parts of this spectrum.
4) The large transmission distances involved between relay and ground stations may require ground transmitter power, antenna sizes, and receiver sensitivities close to the limit of the art. This can cause local interference problems in the vicinity of the ground stations.

It is not the purpose of this paper to suggest that rigorous controls be imposed on the early experimental systems planned for space relay applications. Actually a great deal remains to be learned about satellite technology and space electronics before communication planners will be able to select and exploit the system best suited for their requirements. On the other hand, the potential use of this medium is sufficiently great to warrant some early consideration of the basic factors affecting efficient spectrum utilization and interference. The remainder of this paper is devoted to a preliminary examination of these factors and some predictions about the type of coordination which may ultimately be required when space communications come into being on a broad scale.

TYPES OF GENERAL COVERAGE RELAY SYSTEMS

A number of different satellite relay systems have been proposed for reliable, high-capacity worldwide communications. A brief review of their distinguishing features will be presented. Basically, a number of relays are placed in specified orbits in such a way that a large fraction of the earth's surface is visible to at least one relay, with sufficient coverage overlap to make communication possible between any two points (via suitably located ground relay stations, if multiple hops are required). These relays may be found in a variety of orbits, including equatorial, polar, and inclined. Usually circular orbits are contemplated, but highly eccentric orbits may be utilized for special purposes.

One particular equatorial orbit which has gained con-

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* Original manuscript received by the IRE, December 2, 1959. Presented at the Fifth Natl. IRE-PGCS Communications Symp., Utica, N. Y., October 7, 1959.

† Ramo-Wooldridge, a division of Thompson Ramo Wooldridge, Inc., Los Angeles, Calif.

siderable interest is the so-called 24-hour orbit.[1] A satellite in this orbit has a 24-hour period, so that it appears fixed with respect to a point on the earth's surface. For simplicity, a relay in a 24-hour orbit is often called a 24-hour relay (or satellite).

The relay basically can be either of two types, active or passive. The active relay contains a receiver and transmitter, and reradiates the received signal at a higher power level, either directly or after demodulation and remodulation. The passive relay simply reflects or scatters a portion of the incident energy and, accordingly, does not change the modulation in any way (except for possible distortion effects). Some examples of passive reflectors which have been proposed for use include: 1) large sphere, 2) small spheres or ionized particles, 3) flat plate, and 4) chaff in the form of half-wave dipoles. The large sphere has the advantage of being nondirectional, and may be taken as the standard for comparing the scattering cross section of other reflectors. The half-wave dipole is useful because it achieves a large gain in scattering cross section per unit mass, due to resonance effects. In addition, the scattering from a large number of randomly oriented dipoles is essentially nondirectional. The flat plate, when large, also achieves a large gain in cross section but is extremely directional, a severe limitation for use in a system for worldwide coverage. A summary of the scattering cross section per unit mass for several types of passive reflectors is given in Table I.

TABLE I

SCATTER CROSS SECTION FOR A GIVEN MASS

Type	σ Square m	Relative gain over large spherical shell—db
Large spherical shell 17-meter radius	925	0
100 spherical shells 1.7-meter radius	925	0
2.5×10^6 spherical shells 1.1-cm radius	925	0
3×10^8 spherical shells 10^{-1}-cm radius	6.6×10^{-2}	-41
7×10^{13} solid shot 10^{-3}-cm diameter	2.4×10^{-10}	-126
9.4×10^9 half wave dipoles 10^{-3}-cm diameter	1.9×10^7	$+43$
Flat circular plate 34-meter radius	8.5×10^9	$+70$

Mass = 100 kg of Aluminum
Thickness = 10^{-3} cm
Wavelength = 0.1 meter

In at least one proposed system,[2] a large number of passive relays in orbit is found necessary to ensure complete coverage at all times. This leads to another way of classifying relay systems, *i.e.*, as to whether the relays are "discrete" or "distributed." The former achieves full coverage by optimum positioning of relatively few relays in orbit; the latter by placing a large number of simple small relays in orbit essentially at random. In view of complexity and reliability considerations, a distributed system may be expected to be composed of passive relays.

APPLICATIONS OF ACTIVE AND PASSIVE RELAYS

Since the state of the art indicates the feasibility of both active and passive relays, some idea of the applications for which one is more suited than the other will aid in assessing potential mutual interference problems. This requires a meaningful method for evaluating comparative performance capabilities.

A completely adequate method does not appear to exist, the attempt at evaluation being, in a sense, comparable to a choice between apples and pears. Two methods are suggested here, both based on the requirement to produce equal power densities at the ground receiver. The active relay is characterized for the comparison either by its power gain or by its maximum power output, while the passive relay is described by its scattering cross section. These parameters are sufficient to define the electrical performance of the relays.

The notation employed in the following discussion is:

G_T = gain of ground transmitting antenna,
G_R = gain of ground receiving antenna,
g_s = relay antenna gain, assumed equal for transmitting and receiving (active),
K = relay power gain (active),
σ = scattering cross section illuminated by both ground antennas (passive),
λ = wavelength,
R_1 = distance from ground transmitting station to relay,
R_2 = distance from relay to receiving station,
P_R = received power on the ground,
P_T = transmitted power,
P_s = relay power output.

The received power on the ground for the two kinds of relays may be expressed as

$$P_R = P_T \frac{G_T G_R \lambda^2}{(4\pi)^3 R_1^2 R_2^2} K g_s^2 \frac{\lambda^2}{4\pi} \quad \text{(active)}, \qquad (1a)$$

or

$$P_R = P_s g_s G_R \lambda^2/(4\pi)^2 R_2^2, \qquad (1b)$$

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[1] M. Handelsman, "Performance equations for a stationary passive satellite relay (22,000-mile altitude) for communication," IRE TRANS. ON COMMUNICATIONS SYSTEMS, vol. CS-7, pp. 31–37; May, 1959.

[2] J. R. Pierce and R. Kompfner, "Transoceanic communication by means of satellites," PROC. IRE, vol. 47, pp. 372–380; March, 1959.

depending on choice of characterizing parameter, and

$$P_R = P_T \frac{G_T G_R \lambda^2}{(4\pi)^3 R_1^2 R_2^2} \sigma \quad \text{(passive)}. \tag{2}$$

Comparison of (1) and (2) shows that passive and active relays for the same application may be compared as described above by one of the two equations:

$$\sigma = K g_s^2 \lambda^2 / 4\pi, \tag{3a}$$

or

$$\frac{P_T G_T \sigma}{4\pi R_1^2} = P_s g_s. \tag{3b}$$

This comparison is valid provided that noise in the relay can be neglected; otherwise, the active relay must have a greater ouptut power than indicated by the equations.

To illustrate the approximate "break-even" point between active and passive relays, a numerical example will be presented. Suppose that the relay is 7000 km from the ground terminals, which utilize 35-foot diameter dishes at 3 kmc (48-db gain). The ground transmitter power is taken as 10 kw. The relay, if active, has essentially an omni-directional antenna; if passive, is composed of half-wave dipoles. Then (3b) yields

$$10^{-6}\sigma = P_s.$$

Table I shows that the scattering cross section of randomly oriented half-wave dipoles is about 2×10^5 meter²/kg, for $\lambda = 0.1$ meter. Thus, the active relay will be equivalent to the passive relay, under the conditions assumed, if it has a power-to-weight ratio of

$$P_s = 0.2 \text{ watt/kg}.$$

An examination of possible active relay configurations shows that this value of transmitter power per unit weight appears reasonably typical for systems now under development.

A general comparison of (3a) and (3b) leads to the qualitative conclusions that active relays are to be preferred over passive relays primarily for satellites at great distances, or when high-power ground transmitters and large antenna structures are not available. As a result, without a consideration of mutual interference problems, active relay system design will tend to emphasize low ground power, high relay receiver sensitivity, and a high relay power output. Passive relay systems, on the other hand, may be expected to utilize high ground transmitter power and high ground receiver sensitivity, to overcome limits on the total scattering cross section which can be placed in orbit.

POTENTIAL INTERFERENCE RANGE

The interference problem at the microwave frequencies useful for satellite communication can be severe because of the wide coverage obtained on the ground from high altitudes. Assuming straight-line propagation to the horizon, a satellite will be visible from any point within a circle of radius (measured as degrees of arc along a great circle)

$$r = \cos^{-1} \frac{a}{a+h}, \tag{4}$$

where a = radius of earth and h = altitude of orbit. Thus, any microwave source within this circle is a potential interference source. As examples, satellites at altitudes of 500 miles and 22,000 miles (24-hour orbit), would be visible within circles of radius 27° and 81°, respectively.[3] For an equatorial orbit, r would correspond to the limiting latitude in the northern and southern hemisphere.

In the case of the 24-hour relay, interference reduction by a highly directional antenna in an active satellite is feasible, but requires precise attitude stabilization to maintain contact with a selected ground station. For application in a worldwide communications system, however, high-gain antennas cannot be used in the relay without seriously restricting the service coverage per satellite. Since the earth subtends an angle of about 18° at the altitude of a 24-hour satellite, an antenna gain of about 20 db is the maximum which can be utilized with no restriction in coverage.

SYSTEM CAPACITY WITH HIGH TRAFFIC DENSITY

In contrast to conventional radio relay systems, the relative cost of the relay "installation" will be large, since it involves all the problems of placing satellites in orbit. For maximum benefit to be derived from the investment, it is logical to expect that the relay will be required to serve several terminals simultaneously. If this occurs without global coordination, and if a sufficient number of independent sources exist, the resulting interference problem will be similar to the case of relaying a signal in the presence of excessive random noise. Although this assumption may be pessimistic, it is a valid limitation to discuss, especially since the satellite relay transmission parameters are not easily changed after the orbit is established.

Under these conditions it will be possible to trade information rate in each individual ground terminal to reduce the effect of the interfering signals. Examples of such trades are well known as in the case of PCM, frequency-modulation, etc. Modulation systems of this type exhibit a threshold characteristic which depends on a minimum permissible value of signal-to-interference ratio for proper performance. In principle, a more general limit of trading can be derived from the Shannon formula for information rate,

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[3] The often-used 4/3 correction factor on the earth's radius of 4000 miles has not been introduced here.

$$R = B \log\left(1 + \frac{S}{N}\right) \text{ bits/second,} \tag{5}$$

where B is the signaling bandwidth, S is the average power and N is the total interference power. Under conditions of heavy interference, (5) may be approximated by

$$R = 1.44B\left(\frac{S}{N}\right) \text{ bits/second,} \tag{6}$$

thereby indicating that a linear trade of bandwidth for interference reduction is the best that can be achieved. As an example, consider the capacity available to an individual communication system derivable from a single relay serving a number of other systems. Let C be the capacity, expressed as the number of permissible voice channels with a tolerable SNR of S/N_v per channel, let B denote the total system bandwidth, and B_v the voice channel bandwidth. Then (6) is stated for information rate with and without interference,

$$CB_v\left(\frac{S}{N_v}\right) = B\,\frac{S}{N} \cdot \tag{7}$$

Typical values for the parameters are taken as

$$B = 3000 \text{ mc},$$
$$B_v = 3 \text{ kc},$$
$$S/N_v = 100 \text{ (20 db)}.$$

Table II indicates the resulting number of satisfactory voice channels for various levels of interference. It is obvious from the table that a single relay can be expected to provide a reasonably large capacity, on any given circuit, only if potential sources of interference are properly coordinated so that heavy interference cannot occur. In fact, under severe interference conditions (signal-to-interference ratio less than −10 db) a single TV channel (1000 voice channels) cannot be supported on one circuit.

TABLE II

Capacity per Circuit of a Single Satellite Relay

Number of voice channels	Signal-to-interference ratio
1000	−10 db
100	−20 db
10	−30 db

In practice, the matter is further complicated because the active relay cannot exploit the trade to the extent indicated. Unless demodulation, decoding, and remodulation are employed in the relay (with consequent problems of complexity and reliability) it must exhibit linear transmission properties up to the highest level of interference to be encountered. Thus, for any practical design a limit of tolerable interference level at the relay is inherent, and may be viewed as another type of system threshold. Passive relays, on the other hand, are not subject to such saturation effects, and would permit the types of trade indicated above by manipulation of the ground terminal equipments.

When full coordination of the various sources of radiation is achieved, the single satellite can be fully loaded over its entire available frequency band (within transmitter power limits). The total bandwidth is thus subdivided into noninterfering voice channels, the available number being

$$\text{number of voice channels} = \frac{B}{B_s} = 10^6. \tag{8}$$

Comparison with Table II shows the many orders of magnitude improvement available with the aid of full coordination, a conclusion which applies equally to active relays and discrete passive relays.

Interference from Other High-Power Microwave Sources

Because a satellite relay is visible over a large portion of the earth's surface, as discussed above, interference from high-power microwave transmitters, radar for example, is potentially serious. To indicate the situation that might be encountered, a particular satellite communication system, namely an active relay in a 24-hour orbit, will be examined. An advantage sometimes supposed for the active relay is the relatively low ground power required. This advantage will be examined quantitatively by choice of typical system parameters. Suppose that:

relay antenna gain = 20 db,
ground antenna gain = 40 db,
carrier frequency = 3000 mc,
information bandwidth = 3 mc = 1000 voice channels,
receiver noise figure = 0 db, and
desired SNR = 23 db.

A simple calculation shows that a transmitter power of about 60 watts will suffice when the only limitation on receiver performance is thermal noise.

To assess the potential interference from radar transmitters, a reasonably typical radar set will be presumed with the parameters:

average power = 1 kw,
average antenna gain = 0 db,
emission bandwidth = 1 mc, and
carrier frequency = any point within S band (assumed nominally 2000–5000 mc).

It will be assumed that the various radars visible to the relay are uniformly spread over the 3000-mc band.

The communication system will be considered marginal when the total interference is 20 db below the signal. If n = total number of visible active radars, marginal operation occurs when

$$n\frac{1000\text{ watts}}{3000\text{ mc}/3\text{ mc}} = \frac{60\text{ watts}}{100}\cdot 10^4,$$

or

$$n = 6000.^4$$

Since practically a full hemisphere of the earth's surface is visible to the 24-hour relay, corresponding to an average area of perhaps 25×10^6 square miles, an undesirable level of interference may be expected if the density of active radars exceeds an average of one every 4000 square miles. Correspondingly higher densities must exist to cause excessive interference as the signal level is increased over the minimum requirement.

The radiation received at the relay from interfering sources is much less of a problem with passive relays, because of the higher ground power and antenna gain required to overcome thermal noise. For example, Pierce[2] discusses use of a 100-foot diameter sphere as a passive relay in orbit at 3000 miles altitude. Assuming 70-db antennas at 10 kmc (130-foot diameter), a low-noise receiver (noise temperature = 20°K), and a mean path distance from relay to terminal of 5000 miles, a transmitted power of about 20 kw is necessary to produce a 20-db SNR in a 3-mc bandwidth. Compared with the minimum required power calculated above for the active relay, the effective radiation is about 55 db higher in intensity.

Although interference at the relay does not appear a significant problem with passive satellites, interference radiated directly into the ground receiver may be intolerable. For example, the antenna for the ground receiver in the passive relay system discussed above may have a sidelobe 50 db below the main beam, yielding an effective aperture of only about 10^{-2} square meters. Nevertheless, an interference power comparable to the thermal noise power is intercepted by the sidelobe of the antenna, if the incident power density is about 10^{-13} watts/meter^2. This corresponds to the intensity produced at a 5-mile distance by 0.1 mw radiated isotropically over a line-of-sight path.

It should be noted that the expected condition of radars distributed uniformly over the total available frequency band precludes useful application of the interference reduction techniques previously discussed, since the interference power is directly proportional to the signalling bandwidth used. This offsets exactly the linear trade normally obtained with such techniques. Thus, it may be concluded that complete coordination of the radar and satellite communication frequencies is essential to take advantage of the relatively low power found sufficient for an active relay system, when interference is not present. In addition, coordination may be the only method of preventing overloading when extremely low-noise ground receivers are employed for passive relay systems.

CONCLUSION

The discussion has indicated that simultaneous use of active and passive relay systems with their differing power requirements, and without proper coordination between the two systems, can lead to severe mutual interference. That is, high-power transmitters employed in one system can cause undesirable levels of interference in the receivers of the other system.

When heavy interference is likely with either an active or a discrete passive relay, the capacity of the relay system is severely limited by a requirement for reliable transmission. From a practical point of view, therefore, the ultimate usefulness of active relays for worldwide communication is questionable. Because of the capacity limitation due to interference inherent with discrete relays, the authors foresee a trend toward development of "distributed" passive relay systems. Such systems can provide a large capacity, by virtue of a large number of available reflectors in orbit, with the opportunity for assigning channels on the basis of location of the relay in space as well as radio frequencies.

The calculations indicating possible intolerable interference from radar and other microwave sources further substantiates the probability of a trend away from active relays. Since a low ground-power level does not appear feasible due to the interference level resulting when radars are not under control of a supervising agency, the main advantage of active systems is thereby negated. The great advantage of passive systems, *i.e.*, simplicity of the device in orbit, will, in the authors' opinion, win out for military communication systems, in which reliability is foremost. Thus, the final result of programs to develop a reliable long-range satellite communication system may well be a passive medium having the desirable features of the ionosphere, and few of the disadvantages.

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[4] The presence of harmonic and spurious emissions from the radar sets can effect a reduction of this number. A. H. Ryan, "Control of microwave interference," IRE TRANS. ON RADIO FREQUENCY INTERFERENCE, vol. RFI-1, pp. 1–10; May, 1959.

Passive Satellite Communication*

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Summary—**A number of communications capabilities are noted as desirable goals and the characteristics of passive satellite reflectors are cited as a means of achieving them. Goals noted are the attainment of transoceanic ranges, high communications traffic per satellite, low launching and operating costs, high reliability, simplicity of operation, and long useful life of satellites.**

The properties of various types of passive reflectors are discussed and the characteristics of the sphere are shown to be particularly advantageous. Passive satellite communications systems are compared with current tropospheric scatter systems and are shown to be one order of magnitude better, using power per channel per unit range as a criterion.

Some attention is given to Doppler shift as it bears upon the problem of transmitter-receiver channel coordination, satellite acquisition, and tracking.

I. INTRODUCTION

SINCE the advent of the first Russian Sputnik much has been written, proposed and accomplished in the field of earth satellites. The use of satellites as repeaters for long-range communications systems has been proposed and numerous papers have been presented based upon the use of active satellite repeaters. The emphasis on, and interest in, passive repeaters, however, has lagged and the current literature has largely dealt with the global coverage of various orbit configurations.

The purpose of this paper is not to propose additional system configurations but to examine the feasibility of passive satellite relays in general and to discuss to some extent the approaches available for their realization.

The material will be presented in terms of the characteristics of a single ground point-to-point circuit during the transit of a single relay satellite. The systems problems involving a multiplicity of satellites has been very well treated by Pierce and Kompfner.[1]

The approaches described are directed toward the attainment of the following goals:

1) Attainment of transoceanic ranges of the order of 6000 nm maximum.
2) Availability of the relay to a large number of users.
3) Attainment of a feasible satellite launching cost per channel.
4) Attainment of a feasible operating cost per channel per mile of range.
5) Attainment of a long satellite orbit life.
6) Development of a rapid and simple satellite acquisition and tracking system.
7) Attainment of high satellite reliability by elimination of active mechanical and electronic devices in the satellite.

II. ASSUMPTIONS

All numerical values presented were based on first order feasibility-type calculations. Since no equipment details such as line losses, feed polarizations, etc., were considered, comparable propagation refinements such as radio horizon corrections, Faraday rotation, change of cosmic noise levels with zenith angles, etc., were not included.

The combined effective noise temperature for receiving systems directed from earth to space was assumed to be 10°K,[1] system directed from satellite to earth, 300°K. Signal to noise was always assumed 20 db.

Due to aperture-to-medium coupling losses the maximum gains assumed possible for ground-based antennas was a conservative 50 db.[2] Satellite-borne antennas were assumed to be omnidirectional unless otherwise noted.

The maximum available satellite-borne primary power was assumed to be a maximum of 1 kw for the immediate future. In addition, the maximum radiated power for satellites was assumed to be 100 watts, an efficiency of 10 per cent over all.

A desirable operating spectrum for earth-space systems was assumed to be from 2 to 10 kmc. The lower limit was selected on the basis of antenna aperture and gain considerations as well as ionospheric effects; the upper limit is based on atmospheric abosrption. Discussions of traffic capacities are in terms of channels, a channel being arbitrarily defined as 4 kc. It is further assumed that the circuitry and primary power related to a channel of transmission capacity in a satellite require an average of 5 lbs of total payload. For convenience the carrier frequency for all systems was assumed to be 3 kmc, or $\lambda = 0.1$ meter.

The system configuration assumed for power calculations will consist of the extreme condition of the satellite midway between two ground stations separated by a great circle distance of 6000 nm. This is roughly one fourth the circumference of the earth. If the satellite is to be visible from both stations it must be at an altitude of at least 1600 nm.

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* Original manuscript received by the IRE, December 2, 1959.

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[1] J. R. Pierce and R. Kompfner, "Transoceanic communications by means of satellites," PROC. IRE, vol. 47, pp. 372–380; March, 1959.

[2] Lichman, "Passive Relay Communications," Hughes Aircraft Co., Culver City, Calif., Rept. No. 4551/2; January 9, 1959.

On the average it is expected that the satellite will be in view 10 or 15 degrees either side of the mid-position since ground stations need not be at the extreme range. The slant range from either ground station to the satellite will be 4000 nm. This will be assumed to be the geometric mean range for all calculations. The antenna gain of each ground station will be assumed identical.

Doppler calculations will be based on the average great circle range between stations of 3300 nm. This will provide a maximum mutual visibility of ±15° either side of the mid-point along the great circle arc joining the stations at an altitude of 1600 nm.

III. Passive Relays

All passive satellite relay systems may be characterized by the radar range equation. The energy reflected by the satellite must be received by the distant receiver which, in the communication case, is not situated at the transmitter site. Discounting the possibility of using optical frequencies or higher due to atmospheric absorption effects, ranges will be sufficiently high to place the satellite in the far fields of both transmitting and receiving antennas. Consequently, simplified formulas available in the literature may be used to represent the radar cross section of the satellite.

In addition to the far field criterion, further simplifying assumptions must be made with regard to the satellite dimensions to avoid complexities due to diffraction effects which occur when one or more dimensions of the reflector are less than one wavelength. In general, for this condition, the cross section reduces rapidly as the dimensions become smaller relative to a wavelength although harmonic peaking usually occurs.

The radar range equation for the CW case may be written:

$$P_T = \frac{(S/N)KT_eB(4\pi)^3R^4}{G^2\sigma\lambda^2} \tag{1}$$

where

P_T = average transmitter power, watts
G = antenna gains
R = geometric mean range, nm
T_e = effective noise temperature °K
B = bandwidth, cps
K = Boltzmann's constant
λ = carrier wavelength, nm
σ = satellite cross section, square nm.

In general the cross section, σ, may be viewed as an effective receiving cross section, A_r, multiplied by a retransmission gain G_T:

$$\sigma = A_rG_T. \tag{2}$$

In the cases under consideration here, where dimensions are greater than a wavelength, A_r may be approximated by the physical area projected normal to an incident plane wave. One exception is the very thin half-wave dipole which will have a physical area much less than its electrical capture area.

The cross section of various simple geometrical figures are noted in Table I.[3] This list is far from exhaustive. Many other reflectors may be conceived of, such as dipole arrays which redirect energy to the source (Van Atta array), dipole arrays with internal switching to redirect energy in a desired direction, Luneburg lenses, inverse Luneburg lenses, helices, etc.

TABLE I

	Cross Section	Retransmission Gain	Directive Property
Reflector	σ	G_T	
Half-wave dipole	$\frac{2.9\lambda^2}{4\pi}$	1.7	energy directed normal to long axis
Sphere	A	1	isotropic*
Cylinder	$\frac{\pi LA}{\lambda}$	$\frac{\pi L}{\lambda}$	energy tends to be directed normal to long axis
Flat plate	$\frac{4\pi A^2}{\lambda}$	$\frac{4\pi A}{\lambda^2}$	angle of reflection equals angle of incidence
Parabolic dish, dipole array (broadside)	$\frac{4\pi A^2}{\lambda^2}$	$\frac{4\pi A}{\lambda^2}$	must be directed within one beamwidth of transmitter, return to transmitter
Corner reflector	$\frac{7\pi A^2}{\lambda^2}$	$\frac{7\pi A}{\lambda^2}$	return energy to transmitter

* As an opaque sphere constitutes an obstacle, gain will occur directed back of the sphere along a radial line to the source. Similar effects will occur with irregular obstacles.

Since one of the desired goals noted in the Introduction was the attainment of maximum satellite reliability through the elimination of active devices in the satellites, many of the items noted in Table I may be disqualified.

All of the reflectors have some directional properties, this, of course, being related to the retransmission gain. In most cases, if advantage is to be taken of the gain, some means must be provided, either mechanical or electrical, to redirect the energy to the desired receiver. If these items are discarded, the only remaining devices would be the sphere and corner reflector in Table I and the Van Atta array[4] and inverse Luneburg lens[5] noted in the text.

The inverse[6] Luneburg lens is conceived of as a variable dielectric material which rises to infinity at the center, the incident radiation being returned to the direction from which it was received. Assuming this device is realizable, it is probable that its inherent weight would disqualify it as compared to a spherical nest of corner reflectors. The nested corners could be composed of a lightweight, inflatable metalized plastic.

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[3] "Reference Data for Radio Engineers," International Telephone and Telegraph Corp., p. 804; 1958.

[4] E. D. Sharp, "Properties of the Van Atta Reflector Array," Rome Air Dev. Center, Rome, N. Y., RADC TR-58-53; March, 1958.

[5] R. E. Webster, "Radiation patterns of a spherical Luneburg lens with simple feeds," IRE Trans. on Antennas and Propagation, vol. AP-6, pp. 301–302; July, 1958.

[6] Emerson and Cummings, Inc., Canton, Mass., personal correspondence.

The Van Atta array could also be realized in a lightweight configuration. The dipole elements and interconnections could be plated on a lightweight inflatable balloon structure.

For the system geometry selected it is doubtful that it would be worthwhile to develop a reflector system having gain, yet not require active elements for orientation. In order for the 3-db points of the main return beam to subtend a 6000-mile range, the aperture of the reflector would have to be selected to provide a beamwidth of 2π steradians, a gain of 3 db. Using the corner reflector gain equation of Table I at 3 kmc ($\lambda=0.1$ m), A becomes 10^{-3} square meters. This results in a cross section of 2×10^{-3} square meters.

On the other hand the sphere cross section is substantially independent of wavelength provided its radius exceeds the length of one wavelength. As it is a mechanically symmetrical object in which only the surface is of interest, there is no reason to believe that human ingenuity cannot expand its dimensions to provide extremely high cross sections.

If the 6000-mile great-circle range is to be achieved by the use of a corner-reflector type satellite in synchronous orbit at an altitude of 22,000 nm, the 3-db points of its retransmission beam must subtend 11,200 miles. Its beamwidth is then $\frac{3}{4}$ steradian corresponding to a gain of 16 or 12 db. Using the reasoning employed previously its cross section would be 0.128 square meter. An equivalent sphere would only require 12 db more of cross section or 2 square meters. A much larger sphere could be readily placed in orbit.

The only item in Table I of dimension less than a wavelength is the half-wave dipole. This has the advantage of having a cross section greater than its physical area but has directivity disadvantages as well as a small individual cross section. The treatment of randomly oriented quantities of dipoles is beyond the scope of this paper but is treated in the literature.[7]

IV. Passive vs Active

No doubt the reader is concerned with the fact that passive satellite reflectors are even being considered. It is obvious to everyone familiar with transmission systems that only minute quantities of power are required for active systems as compared to passive. This question will be examined a little more critically here.

The active and passive satellite relay system for the specific configuration assumed here may be readily compared by the use of the range equations for the two systems. The range equation for the passive system is already stated in (1), which gives the ground transmitter radiated power requirement. The range equation giving the ground radiated power requirement for the active case need only consider the one-way requirement from ground to satellite. This is

$$P_T = \frac{(S/N)KT_eB(4\pi R)^2}{G\lambda^2}. \tag{3}$$

Eq. (3) has been written subject to the previously stated assumptions of unity gain for the satellite antenna and the system configuration described. The symbols have the same meaning and units as noted in connection with (1).

The technique of comparison will be to assume that the design parameters of both systems are identical, including the ground radiated power. The effective receiver noise temperatures must be different in accordance with the assumptions. Eq. (3) will then be divided by (1) and the appropriate cancellation performed. The resulting relationships will then specify the cross section of the passive satellite required to match the performance of the equivalent active system.

$$\sigma = 4\pi\left(\frac{T_{ep}}{T_{ea}}\right)\frac{R^2}{G}. \tag{4}$$

The subscripts p and a refer to the passive and active systems respectively. Substitution of the assumed parameters yields a required cross section of approximately 60 square miles.

It is doubtful if such a reflector cross section will be realizable within the next decade or more. At present lightweight inflatable balloons of 100 feet in diameter have been fabricated and will be launched into 1000-mile-high orbits within the next year.[8] It is probable that 1000-foot-diameter balloons will eventually be placed in orbit. The cross section of such a reflector will be 2.1×10^{-2} miles. A foreseeable passive system requiring no active equipment in the satellite will then require 34 db of system gain over the active systems in order to match the capability of active systems. A passive system using 100-foot-diameter spheres will require 54 db of additional system gain.

At first glance the above figures appear to reinforce the intuitive judgement of the communication engineer that passive systems are not feasible. However, before discarding them on this basis one should inquire as to the current value placed upon the attainment of long-range communications.

There are many areas of the world where it is not feasible, desirable, or even possible to reliably bridge long ranges by wire, transoceanic cable, a multiplicity of microwave links or HF. In order to meet this need, tropospheric and ionospheric forward-scatter systems have been developed and placed in operation at great expense.

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[7] Van Vleck, Bloch, and Hamermesh, "Theory of radar reflections from wires or other metallic strips," *J. Appl. Phys.*; March, 1947.

[8] "Next decade in space," *Aviation Week*; June 22, 1959.

The premium placed upon long range communications in terms of required radiated power per channel per mile of range may be readily calculated, for example, for a tropospheric scatter system having a range of 400 nm. Current literature[9] indicates that such a system will have a loss of 98 db in excess of free space, and will require 3.3 kw per channel of 4-kc bandwidth.

Eqs. (1) and (3) may be used to calculate power required per channel per mile of range. For satellite systems these calculations are summarized in Table II.

TABLE II

System Type	Radiated Power/Channel	Power per Channel Mile
Active satellite, satellite-to-ground circuit	0.43 mw	0.07 μw
Active satellite, ground-to-satellite circuit	13 mw	2.5 μw
Passive satellite, 100-foot-diameter sphere	3.9 kw	0.6 w
Passive satellite, 1000-foot-diameter sphere	39 w	5 mw
Tropospheric scatter, 400-mile range	3.3 kw	8.2 w

Table II shows that, although the 100-foot satellite is not competitive with an active system, it is certainly competitive with a tropospheric scatter system. The 15 scatter links required for a 6000-mile range would require a total expenditure of 495 kw as compared to 3.9 kw for the passive system.

In terms of availability of power sources and the value attached to long-range communications systems as evidenced by the development of scatter systems, it is apparent that a passive system based upon the use of 100-foot-diameter spheres is feasible.

V. TRAFFIC CAPACITIES

A desirable goal is the attainment of a maximum traffic capacity through the realization of a large number of individual channels per satellite relay. This enhances its value in terms of the number of users to which it may be made available.

It was pointed out under the assumptions that a spectral space extending from 2 to 8 kmc should be available based on propagation and antenna size considerations.

The passive spherical satellite will be capable of handling channels allocated throughout this space, as its cross section is essentially not dependent on frequency. As noted, its cross section is frequency dependent when wavelengths become comparable to diameter. In the case of the 100-foot-diameter sphere this would reduce the lower frequency end into the HF region of the spectrum. The upper-frequency limit would probably be based upon the surface irregularities due to the practical fabrication difficulties. The upper propagation band of 10 kmc would require that these irregularities be considerably less than 3 cm to avoid phase cancellation and multipath.

If 50 per cent of the 8-kmc spectral space available is used for 4-kc channels, the traffic capacity of the passive spherical satellite system would be one million channels.

Available data on the 100-foot-diameter sphere being developed by NASA indicates that its weight will be approximately 100 pounds.[10] As surface area of the sphere having constant weight per unit surface rises with the square of diameter, a 1000-foot-diameter balloon should weigh five tons. It is probable that payloads of this magnitude will be capable of being placed in orbit within the next few years.

If five tons is considered to be a reasonable payload within the foreseeable future, this number may be used in estimating the feasible number of channels of an active satellite repeater. For this purpose it will be assumed that total antenna primary power casing, frequency standards, microwave oscillators and associated circuitry required per channel in an active satellite relay will result in an average weight of five pounds per channel. On this basis the traffic capacity per satellite would be 2000 channels.

In terms of the passive satellite of 1000-foot-diameter the average weight per channel would be 0.16 ounce or 4.5 grams, less than the weight of a one-karat jewel. It is difficult to conceive of an active system of comparable channel capacity being developed in the foreseeable future.

VI. LONGEVITY

With the exception of the solid dielectric type reflectors, the passive satellite reflectors considered are concerned only with electromagnetic reflecting surfaces of the order of 1000 angstroms thick. One intuitively feels that drag effects, even in the tenuous atmosphere of space, should disturb the orbits of such objects. Quantitative analyses of the orbit of low-density satellites must consider the particle density estimates derived from sounding rockets, the aerodynamics of objects in these low-density atmospheres and the orbit perturbations determined by the numerical integration with time of the resulting drag forces. Since orbit parameters in the simple two-body case are determined by the total particle energy per unit mass, a useful parameter in such calculations is the ratio of the projected area, normal to velocity, to the mass of the satellite.

By ordinary drag theory the loss of kinetic energy per unit mass for each orbit revolution is the product of a constant and the ratio of area to mass. This loss of kinetic energy has the effect of making the total energy more negative, which is the equivalent of reducing the radius of a circular orbit. Every reduction of energy increases the drag forces at a lower altitude and the vehicle gradually spirals into the dense atmosphere and burns up.

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[9] "Reference Data for Radio Engineers," International Telephone and Telegraph Corp., p. 761; 1957.

[10] NASA data; June, 1959.

Calculations based on best estimates of high-altitude atmospheric densities indicate the life[11] of a 100-pound, 100-foot-diameter balloon to be 25 years for an orbit having an apogee of 1600 miles and a perigee of 1000 miles altitude. A similar solid dielectric sphere having roughly the density of water would have a weight of about 300 tons and consequently have a much greater life. On the other hand should the balloon orbit perigee be only 500 miles, its life expectancy would be only 2 months.

By contrast, using a linear approximation for the solid dielectric sphere, its life for a 500-mile perigee would be 1000 years.

In the case of the solid satellite, experience would indicate that micrometeoric erosion does not constitute a problem (with the possible exception of its effect on solar power cells). On the other hand, one would expect a considerable effect in the case of the balloon-type reflector composed of rather diaphanous structural material supporting a thin metallic reflecting film. No doubt considerable experience will have to be gained through the actual launching of balloons into orbit before a suitably rigidized lightweight balloon can be launched with a realistic life expectancy of several years.[12]

The above considerations of life-limiting factors do not reveal any fundamental limitations. In the final analysis a spherical reflecting satellite of arbitrarily low ratio of area to mass, fabricated of stainless steel, if necessary, may be placed in a virtually permanent orbit. The fundamental limitation in this case is, of course, the state of the development of rocket technology and the availability of the economic resources necessary to launch massive bodies into orbit.

VII. Acquisition and Tracking

There are various approaches to this problem depending upon the orbit system configuration adopted. In this case it is assumed that the ground stations are separated by 3300 nm. The detailed geometry of the configuration is described in the Appendix.

It will be assumed that the satellite schedules of arrival over the horizon are known within $\pm 2.5°$ of the calculated position and within a few seconds in time. The assumed antenna gain of 50 db at 3 kmc provides a beamwidth of $\frac{1}{2}°$. A channel operating at 300 mc will provide a gain of 30 db with the same antenna at a beamwidth of 5°.

It is demonstrated in the Appendix that the Doppler frequency changes approximately linearly from acquisition to release. The radius of the circle of mutual visibility is about 1200 miles. The slant range to the satellite will be about 3600 miles, which at a 5° beamwidth subtends about one fourth of the zone through which the satellite will pass. As the upper Doppler frequency shift is 93 kc, this shift should change over the first quarter of the shift down, or 23 kc.

In order to assure Doppler acquisition, the 4-kc tracking bandwidth could be located in discrete bands throughout the 23-kc band in order to assure frequency acquisition. It is shown in the Appendix that the minimum bandwidth required for acquisition is 53 cps. Use of four 100-cps bandwidth filters should allow ample acquisition bandwidth. At a 10-db signal-to-noise ratio the power required would be 3.9 kw.

Having acquired the satellite in both space and frequency the tracking circuit may lock on and follow. Under tracking conditions the Doppler bandwidth may be narrowed considerably for a higher signal-to-noise margin. Standard multiple interferometric or conical scanning techniques may be used. Communications receiving channels may be locked to the tracking frequency so that automatic coordination between transmitting and receiving frequencies is effected. The effect of Doppler shifts on expanding or contracting transmitted bandwidths is shown in the Appendix to be negligible.

VIII. Conclusion

The use of individual passive satellites as reflecting media for transmission of microwave communications over ranges from 3000 to 6000 miles has been examined from the point of view of attaining a series of desirable goals. It is concluded that the lightweight spherical satellite provides communication for a large number of users on a weight per channel basis which cannot be met in the foreseeable future by existing active satellite repeater techniques. In addition, due to the absence of active satellite-borne components, it has a reliability feature which cannot be matched by other types of systems.

The attainment of long satellite orbit life of the order of decades will require extensive development but no fundamental scientific difficulties must be overcome.

The operating cost per channel per mile of range will be initially one order of magnitude better than present state-of-the art long-range tropospheric scatter systems and may be greatly improved through the development of large diameter satellites and ground antennas having gain through the atmosphere in excess of 50 db.

Satellite acquisition tracking and channel frequency coordination may be accomplished by the adaptation of Doppler state-of-the art techniques.

Appendix

Doppler Calculations

System Geometry

Satellites have been assumed to be on the surface of a sphere of altitude Z_0. Transmitter and receiver station

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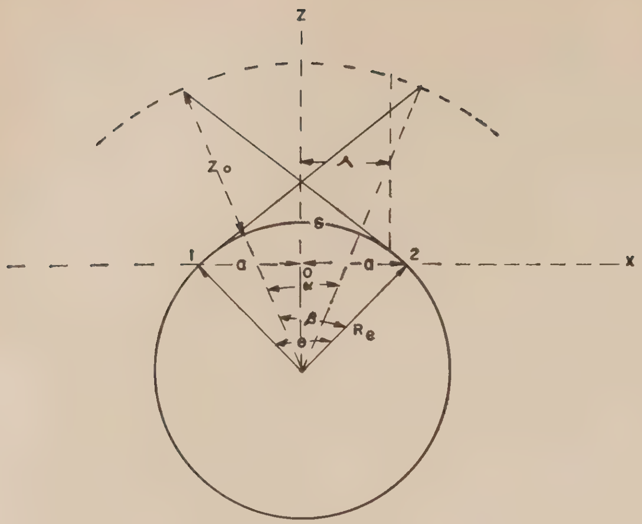
[11] NASA data, June, 1958.

[12] Recent unpublished analyses of the effects of solar radiation pressure on the orbits of low average density satellites indicate a life limitation because of this factor. These calculations show strong dependence of the life on the satellite on altitude and inclination of the orbit plane to that of the earth's equation. However, in the case of 100-foot-diameter balloons having altitude of 1600 nautical miles, inclined as much as 30° to the Equator, solar radiation pressure appears to have only a negligible effect on longevity.



S = great circle distance between stations 1 and 2
θ = angle subtended at center of earth by station 1 and 2
β = horizon range of satellites in angular measure
α = range of satellite mutual visibility in angular measure
r = mean radius of mutual visibility
a = semichord range between station 1 and 2
R_e = radius of earth
Z_0 = altitude of satellites

Fig. 1.

are shown in Fig. 1 at points 1 and 2. Given:

$$R_e = 4000 \text{ nm}$$

$$S = 3260 \text{ nm}.$$

Find: r and a;

$$\theta = \frac{S}{R_e} \tag{1}$$

$$a = R_e \sin \theta/2 \tag{2}$$

$$r = \left(R_e + \frac{Z_0}{2}\right)\left(\frac{\alpha}{2}\right) \tag{3}$$

$$\alpha = \theta - 2(\theta - \beta) \tag{4}$$

$$\beta = \cos^{-1} \frac{R_e}{R_e + Z_0}. \tag{5}$$

Then

$$r = 1200 \text{ nm maximum}$$

$$a = 1960 \text{ nm}.$$

Doppler Geometry

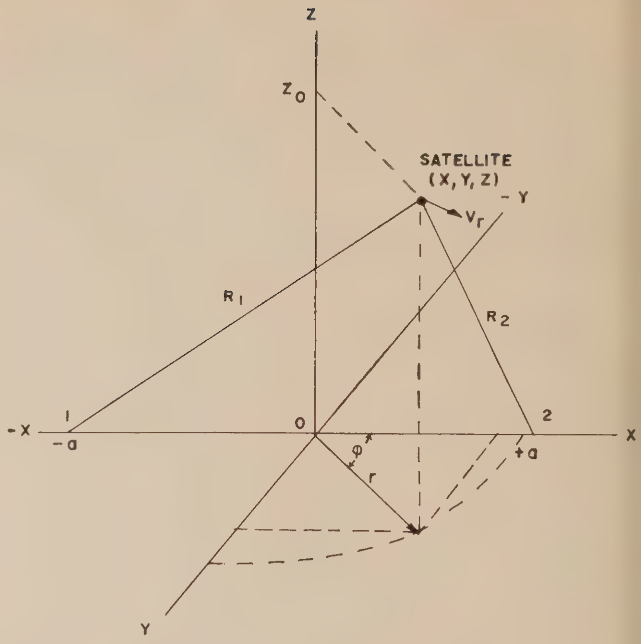
A Cartesian coordinate system is used based upon parameters derived from Fig. 1. This system is shown in Fig. 2.

The radial velocity components may be obtained from the total derivative with respect to time for the radial ranges:

$$R_1{}^2 = Z_0{}^2 + y^2 + (x + a)^2 \tag{6}$$

$$R_2{}^2 = Z_0{}^2 + y^2 + (x - a)^2 \tag{7}$$

$$R_1 V_{r_1} = vV_y + (x + a)V_x \tag{8}$$



v_r = velocity of satellite approximated as parallel to XY plane
r = displacement of satellite along V_r direction from 0
ϕ = angle of intersection of satellite path to chord between stations 1, 2
R_1 = range from station 1 to satellite
R_2 = range from station 2 to satellite

Fig. 2.

$$R_2 V_{r_2} = yV_y + (x - a)V_x. \tag{9}$$

Cylindrical coordinates may be derived based upon the transformations:

$$X = r \cos \phi \tag{10}$$

$$V_x = V_r \cos \phi \tag{11}$$

$$V = r \sin \phi \tag{12}$$

$$V_y = V_r \sin \phi. \tag{13}$$

The transformed equations become

$$R_1{}^2 = Z_0{}^2 + r^2 + a^2 + 2ar \cos \phi \tag{14}$$

$$R_2{}^2 = Z_0{}^2 + r^2 + a^2 - 2ar \cos \phi \tag{15}$$

$$R_1 V_{r_1} = rV_r + aV_r \cos \phi \tag{16}$$

$$R_2 V_{r_2} = rV_r - aV_r \cos \phi. \tag{17}$$

Doppler Shifts

The approximate Doppler shifted frequency, f_s, reflected from the satellite, will be related to the frequency, f_1, transmitted from station 1 by

$$f_s = f_1\left(1 + \frac{V_{r_1}}{c}\right). \tag{18}$$

The Doppler shifted frequency f_2 received at station 2 will be

$$f_2 = f_s\left(1 + \frac{V_{r_2}}{c}\right). \tag{19}$$

Relating f_2 to f_1,

$$f_2 = f_1\left(1 + \frac{V_{r_1}}{c}\right)\left(1 + \frac{V_{r_2}}{c}\right) \tag{20}$$

$$f \approx f_1\left(1 + \frac{V_{r_1} + V_{r_2}}{c}\right). \tag{21}$$

The net Doppler shift between station 1 and 2 will be

$$\Delta f = (f_2 - f_1) = f_1\left(\frac{V_{r_1} + V_{r_2}}{c}\right). \tag{22}$$

Substituting the previously derived expressions yields

$$\Delta f \approx \frac{f_1 r V_r}{R_1 R_2 c}\left[(R_1 + R_2) + (R_2 - R_1)\frac{a}{r}\cos\phi\right]. \tag{23}$$

The values of the squares of the ranges may be written

$$R_1^2 = Z_0^2\left[1 + \left(\frac{a}{Z_0}\right)^2 + \left(\frac{r}{Z_0}\right)^2 + \frac{2ar\cos\phi}{Z_0^2}\right] \tag{24}$$

$$R_2^2 = Z_0^2\left[1 + \left(\frac{a}{Z_0}\right)^2 + \left(\frac{r}{Z_0}\right)^2 - \frac{2ar\cos\phi}{Z_0^2}\right]. \tag{25}$$

For the case where $r \lesssim \frac{1}{5} Z_0$, the ranges may be approximated as

$$R_1^2 = R_2^2 \approx Z_0^2 + a^2. \tag{26}$$

Under this condition

$$\Delta f \approx \frac{\pm 2 f_1 r V_r}{\sqrt{Z_0^2 + a^2}\,c} \approx \frac{\pm 2 f_1 r V_r}{\sqrt{2} Z_0 c}$$

$$0 \leq r \leq 300 \text{ nm}, \quad Z_0 \approx a. \tag{27}$$

For the case where

$$\phi = \pm 90°$$

$$R_1^2 = R_2^2 = Z_0^2 + a^2 + r^2 \tag{28}$$

and

$$\Delta f = \frac{2 f_1 r V_r}{\sqrt{3} Z_0 c}$$

$$300 \leq r \leq 1200 \text{ nm max}$$

$$Z_0 \approx a \approx r. \tag{29}$$

For the case where

$$\phi = 0 \text{ or } 180°$$

$$R_1^2 = Z_0^2 + a^2 + r^2 \pm 2ar \tag{30}$$

$$R_2^2 = Z_0^2 + a^2 + r^2 \pm 2ar. \tag{31}$$

Using the assumed values:

$$R_1 \approx \sqrt{5} Z_0 \tag{32}$$

$$R_2 \approx Z_0 \tag{33}$$

and

$$\Delta f \approx \pm \frac{2 f_1 r V_r}{\sqrt{5} Z_0 c}$$

$$300 \leq r \leq 1200 \text{ nm max}$$

$$Z_0 \approx a \approx r. \tag{34}$$

If the origin of time is selected as the origin of r the Doppler shift may be written for the intervals of approximations from the relationship of r, velocity, and time. Grossly approximating the function over the entire interval by (27),

$$\Delta f = \frac{\sqrt{2} f_1 V_r^2 t}{Z_0 c} \tag{35}$$

$$f_1 = 3 \text{ kmc}$$

$$c = 3 \times 10^5 \text{ km/second}$$

$$V_r = 6.66 \text{ km/second}$$

$$Z_0 = 2970 \text{ km}$$

$$t = s$$

$$\Delta f = 280t \text{ cps}$$

$$t_{\max} = \pm 334 \text{ seconds}$$

$$\Delta f_{\max} = 93.5 \text{ kc}. \tag{36}$$

In terms of a relative frequency shift,

$$\frac{\Delta f}{f} = 9.3 \times 10^{-8} t$$

$$\left(\frac{\Delta f}{f}\right)_{\max} = 3.1 \times 10^{-5}. \tag{37}$$

Doppler Bandwidth

The minimum bandwidth which may be used to detect a signal which is changing in time may be approximated as[13]

$$B = \sqrt{\frac{df}{dt}}\,. \tag{38}$$

Based on (36) the theoretical Doppler bandwidth of the receiver would be 53 cps. Assuming the use of a frequency standard which provides precision of one part in 10^9 at 3 kmc, the signal could be defined within this band to ±3 cps.

Relative radial velocity between source and receiver will also influence the bandwidth of the transmitted signal. If B_t is the bandwidth, the apparent bandwidth will be

$$B_a = B_T \frac{\Delta f}{f}\,. \tag{39}$$

Using the maximum relative Doppler frequency shift noted previously for a 4-kc channel, the Doppler compression or expansion will be 0.12 cps. Consequently little error will occur in simply considering the entire bandwidth to be translated with the carrier frequency.

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[13] L. N. Ridenour, "Radar System Engineering," McGraw-Hill Book Co., Inc., New York, N. Y., p. 137; 1947.

The Use of a Passive Spherical Satellite for Communication and Propagation Experiments*

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Summary—The use of a passive satellite for over-the-horizon communication links has been proposed by Pierce and Kompfner. To confirm the theoretical work which has been done to date, NASA is planning to launch an aluminum coated, 100-foot-diameter plastic sphere for such a communication relay. In addition to confirming the feasibility of a communication link, the NASA sphere can be instrumental in confirming theoretical work in UHF propagation characteristics. With regard to conducting propagation studies, an essential requirement is that the sphere's scattering properties be described in advance of the experiment. The scattering properties of a metallic sphere (whose radius is very large with respect to the wavelength of the incident radiation) are described in this article. It is shown that the sphere's scattered field pattern is a function of the incident radiation's polarization scheme, and that the choice of any particular polarization scheme depends upon the experiment to be performed.

In a recent article[1] Pierce and Kompfner discussed the efficacy of over-the-horizon communication by means of forward scatter of UHF radiation by a spherical satellite. An aluminum coated plastic sphere (100 feet in diameter) has been developed by NASA for use as a satellite and will be employed as a reflector in a passive communication link.

The exploration of outer space has created renewed interest in propagation effects at UHF and higher frequencies. The relative freedom from atmospheric and ionospheric effects of UHF and SHF radiation has brought this frequency range into prominence for use in communication with and control of space vehicles. Optimum utilization of tracking systems will require extensive knowledge of propagation phenomena. The spherical satellite will provide a medium by which it will be possible to re-evaluate some of the theoretical expressions which go into the make-up of space link calculations.

Knowledge of the reflection properties of the passive satellite will permit the experimental determination of propagation effects. By using the satellite to scatter energy into regions where the primary radiation is not present, effects such as atmospheric loss, fading margins, refraction, and Faraday rotation can be recorded on a continuous basis. More precise statistical data can then be derived to correlate the changes in effects with elevation angle, sun activity, and, in certain special cases, latitude and azimuth angle. Assuming that the scattering properties of the sphere are defined, the design of the necessary experiments is relatively straightforward.

With an aluminum coating several millimeters thick and under illumination by UHF (or higher frequency) radiation, the NASA sphere's scattering properties are essentially those of a high conductivity, fully metallic sphere. At 300 mc, for instance, an aluminum sphere has a skin depth of 5×10^{-3} cm and a skin effect resistance of 5×10^{-3} ohms. The distributions of scattered energy shown in this article were acquired through solution of the classic equations of Mie[2] for the field components. The exact method by which these solutions were acquired can be found in the Appendix.

When the incident plane (see Fig. 1) is linearly polarized, say along the x axis, its field components are expressible in spherical coordinates as

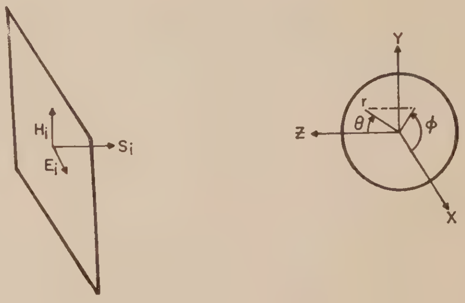

Fig. 1—Incident plane wave.

$$\overline{E}_i = E_0 e^{-i\omega t}(\sin\theta\cos\phi\hat{r} + \cos\theta\cos\phi\hat{\theta} - \sin\phi\hat{\phi})e^{ikr\cos\theta}, \quad (1)$$

$$\overline{H}_i = H_0 e^{-i\omega t}(\sin\theta\sin\phi\hat{r} + \cos\theta\sin\phi\hat{\theta} + \cos\phi\hat{\phi})e^{ikr\cos\theta}; \quad (2)$$

and the radial component of their Poynting vector as

$$S_i = P_0 \cos\theta, \quad (3)$$

where

$$P_0 = \frac{E_0 H_0}{2} = \frac{kE_0^2}{2\omega\mu}.$$

Series solutions, as constructed by Mie and others,[3] are for the scattered field components,

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* Original manuscript received by the IRE, December 2, 1959; revised manuscript received, January 4, 1960.

† Philco Western Development Laboratories, Palo Alto, Calif.

[1] J. R. Pierce and R. Kompfner, "Transoceanic communication by means of satellites," Proc. IRE, vol. 47, pp. 372–380; March, 1959.

[2] J. A. Stratton, "Electromagnetic Theory," McGraw-Hill Book Co., Inc., New York, N. Y., pp. 563–573; 1941.

[3] H. Bateman, "The Mathematical Analysis of Electrical and Optical Wave-Motion," Dover Publications, New York, N. Y.; 1955.

$$\overline{E}_s = E_0 e^{-i\omega t} \sum_{n=1}^{\infty} (i)^n \left[\frac{2n+1}{n(n+1)}\right] \Bigg\{ A_n \left[\frac{\cos\phi}{\sin\theta} P_n'(\cos\theta) h_n(kr)\hat{\theta} - \sin\phi \frac{dP_n'(\cos\theta)}{d\theta} h_n(kr)\hat{\phi}\right]$$

$$- iB_n \left[\frac{n(n+1)}{kr} \cos\phi P_n'(\cos\theta) h_n(kr)\hat{r} + \frac{\cos\phi}{kr} \frac{dP_n'(\cos\theta)}{d\theta} \frac{d}{d(kr)} [krh_n(kr)]\hat{\theta}\right.$$

$$\left. - \frac{\sin\phi}{kr\sin\theta} P_n'(\cos\theta) \frac{d}{d(kr)} [krh_n(kr)]\hat{\phi}\right]\Bigg\}, \qquad (4)$$

$$\overline{H}_s = -\frac{kE_0}{\omega\mu} e^{+i\omega t} \sum_{n=1}^{\infty} (i)^n \left[\frac{2n+1}{n(n+1)}\right] B_n \left[-\frac{\sin\phi}{\sin\theta} P_n'(\cos\theta) h_n(kr)\hat{\theta} - \cos\phi \frac{dP_n'(\cos\theta)}{d\theta} h_n(kr)\hat{\phi}\right]$$

$$+ iA_n \left[\frac{n(n+1)}{kr} \sin\phi P_n'(\cos\theta) h_n(kr)\hat{r} - \frac{\sin\phi}{kr} \frac{dP_n'(\cos\theta)}{d\theta} \frac{d}{d(kr)} [krh_n(kr)]\hat{\theta}\right.$$

$$\left. + \frac{\cos\theta}{kr\sin\theta} P_n'(\cos\theta) \frac{d}{d(kr)} [krh_n(kr)]\hat{\phi}\right]\Bigg\}; \qquad (5)$$

where

$P_n'(\cos\theta)$ = first degree, nth order associated Lengendre polynomial,
$h_n(kr)$ = nth order Hankel function,
k = propagation constant,
r = distance from center of sphere,
μ = permeability of propagating medium,
ω = radian frequency.

When the sphere has a high conductivity surface and a radius large with respect to wavelength, the boundary conditions for its surface dictates that

$$A_n = -\frac{j_n(ka)}{h_n(ka)}, \quad B_n = -\left[\frac{\dfrac{d}{d(kr)}[krj_n(kr)]}{\dfrac{d}{d(kr)}[krh_n(kr)]}\right]_{r=a}, \qquad (6)$$

where

$jn(ka)$ = nth order spherical Bessel function,
a = radius of sphere.

Subsitution of (6) into (4) and (5) yields the following far zone field solutions:

$$\overline{E}_s = \frac{a}{r} E_0 e^{i[k(r-a)-\omega t]} \left\{-\left(\frac{1}{kr}\right)\sin\theta\cos\phi\hat{r}\right.$$

$$\left. - \cos\theta\cos\phi\hat{\theta} + \sin\phi\hat{\phi}\right\} e^{ika\cos\theta}, \quad (7)$$

$$\overline{H}_s = \frac{a}{r} \frac{kE_0}{\omega\mu} e^{i[k(r-a)-\omega t]} \left\{-\left(\frac{1}{kr}\right)\sin\theta\sin\phi\hat{r}\right.$$

$$\left. - \sin\phi\hat{\theta} - \cos\theta\cos\phi\hat{\phi}\right\} e^{ika\cos\theta}. \quad (8)$$

Since the radial component of the far zone field is an inverse function of r^2, it can be neglected in the evaluation of the total far zone Poynting vector,

$$\overline{S}_s = \left(\frac{a}{r}\right)^2 P_0(1 - \sin^2\theta\cos^2\phi)\hat{r}. \qquad (9)$$

The pattern of Fig. 2 is a surface of revolution about the x axis and has the same form as the radiation pattern of a quarter wave dipole antenna.

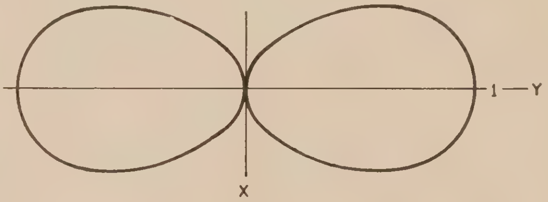

Fig. 2—Scattered energy in sphere's equatorial plane (linear polarization).

If one assumes the incident energy to be linearly polarized along the y axis, the scattered energy distribution is a surface of revolution about the y axis and, in general, the null of the scattered energy distribution can be seen to align itself with the incident polarization vector. When the incident energy is linearly polarized, the scattered field will also be linearly polarized. By control of the spatial orientation of the transmitting and receiving elements, the amount of energy communicated in the link can be maximized (provided that the effects of Faraday rotation can be compensated for).

The field distributions for circular polarization were computed by introducing space quadrature terms and a phase angle parameter β into (1) and (2); hence,

$$\overline{E}_i = E_0 e^{i\omega t}[(\cos\theta\cos\phi + \cos\theta\sin\phi e^{i\beta})\hat{\theta}$$

$$- (\sin\phi - \cos\phi e^{i\beta})\hat{\phi}] e^{ikr\cos\theta}, \quad (10)$$

$$\overline{H}_i = H_0 e^{i\omega t}[(\cos\theta\sin\phi - \cos\theta\cos\phi^{i\beta})\hat{\theta}$$

$$+ (\cos\phi + \sin\phi e^{i\beta})\hat{\phi}] e^{ikr\cos\theta}. \quad (11)$$

The scattered field components were then

$$\overline{E}_s = \frac{a}{r} E_0 e^{i[k(r-a)-\omega t]}\left[-(\cos\theta\cos\phi + \cos\theta\sin\phi e^{i\beta})\hat{\theta} \right.$$

$$\left. + (\sin\phi - \cos\phi e^{i\beta})\hat{\phi}\right] e^{ika\cos\theta}, \quad (12)$$

$$\overline{H}_s = \frac{a}{r}\frac{kE_0}{\omega\mu} e^{i[k(r-a)-\omega t]}\left[-(\sin\phi - \cos\phi e^{i\beta})\hat{\theta}\right.$$

$$\left. - (\cos\theta\cos\phi + \cos\theta\sin\phi e^{i\beta})\hat{\phi}\right] e^{ika\cos\theta}, \quad (13)$$

and the far zone Poynting vector,

$$\overline{S}_s = \left(\frac{a}{r}\right)^2 \frac{P_0}{2}(1 + \cos^2\theta - \sin 2\phi \sin^2\theta\cos\beta)\hat{r}. \quad (14)$$

The case of circular polarization results from a substitution of $\beta = \pm\pi/2$ in (12), (13), and (15), whereupon the Poynting vector becomes

$$\overline{S}_s = \left(\frac{a}{r}\right)^2 \frac{P_0}{2}(1 + \cos^2\theta)\hat{r}. \quad (15)$$

The energy distribution of Fig. 3 is a surface of revolution about the z axis. The scattered energy is itself circularly polarized. The values of $\pi/2$ and $-\pi/2$ for β produce an off-set, linearly polarized wave as shown in Fig. 4; these patterns are surfaces of revolution about the $y = -x$ and $y = x$ axes, respectively. For intermediate values of β the patterns will be oriented about the $y = -x$ or $y = x$ axes and will exhibit elliptic polarization.

The free-space loss formula given by Pierce and Kompfner, to be consistent with the distributions of this article, will now read

$$L = \frac{P_t}{P_r} = \frac{\lambda^2 p^4}{A^2\eta^2 a^2 G}, \quad (16)$$

where

P_t = transmitter power,
P_r = receiver power,
λ = wavelength,
p = geometric mean of the distances between the satellite and the terminals,
A = antenna area (assumed to be the same for both transmitter and receiver),
η = antenna efficiency,
a = radius of sphere,
G = gain of the sphere.

The following form was used for the radar cross section of the sphere:

$$\sigma = 4\pi\frac{S_s}{S_i} = 4\pi a^2 G. \quad (17)$$

The factor G in (17) has a maximum of 0 db for the distributions of this article. An alternate approach would be to compare the scattering of the sphere with that of an isotropic scatterer. The gain of the sphere over an isotropic scatterer is computed in the Appendix and has a maximum of 1.1 db when linear polarization is used. When circular polarization is used the distribution has a maximum of 1.3 db and a minimum of −1.3 db.

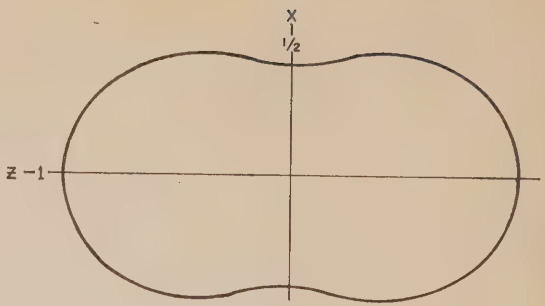

Fig. 3—Scattered energy in sphere's polar plane (circular polarization).

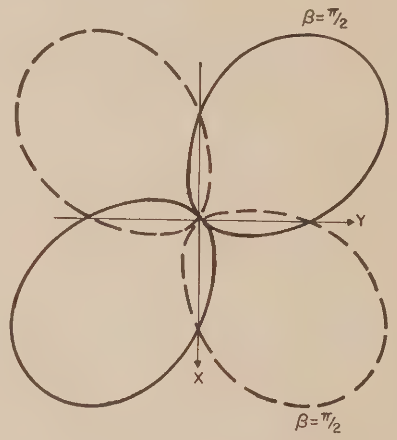

Fig. 4—Switching the field pattern.

Scattering distributions acquired by other investigators[4,5] indicate that the sphere primarily back scatters and forward scatters when the sphere radius is of the order of magnitude of the incident radiation's wavelength. Their published observations were for $a = 3\lambda$ or less, whereas a sphere radius to wavelength parameter of an order of magnitude greater than that just stipulated is pertinent in the UHF region. It would appear that operation of the 100-foot sphere for the experiments mentioned in this article is limited to the region above 100 mc.

The total far zone energy distributions can be obtained from the various field quantities given in this article when both the incident and scattered fields are present. In the case of over-the-horizon communication it is presumed that the incident field energy will not be present, so that expressions (9), (14), and (15) are of principal interest.

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[4] C. I. Beard and V. Twersky, "Propagation through random distributions of spheres," 1958 IRE WESCON CONVENTION RECORD, pt. 1, p. 94.

[5] J. S. Honda, "Scattering of microwaves by figures of revolution," 1957 IRE WESCON CONVENTION RECORD, pt. 1, pp. 151–157.

APPENDIX

A. Solution of the Series

Insertion of (6) into (4) and (5) leads to expressions of the form

$$1)\ h_n(kr)\left[-\frac{j_n(ka)}{h_n(ka)}\right],$$

$$2)\ h_n(kr)\left[-\frac{\dfrac{d}{d(kr)}\,[krj_n(kr)]}{\dfrac{d}{d(kr)}\,[krh_n(kr)]}\right]_{r=a}$$

$$3)\ \frac{d}{d(kr)}\,[krh_n(kr)]\left[-\frac{j_n(ka)}{h_n(ka)}\right],$$

$$4)\ \frac{d}{d(kr)}\,[krh_n(kr)]\left[-\frac{\dfrac{d}{d(kr)}\,[krj_n(kr)]}{\dfrac{d}{d(kr)}\,[krh_n(kr)]}\right]_{r=a};$$

and using

$$h_n(kr) = \frac{e^{ikr}}{i(kr)}\, i^{-n} \sum_{m=0}^{n} \frac{(n+m)!}{m!(n-m)!}\left(\frac{i}{2(kr)}\right)^m, \tag{18}$$

one obtains

$$1)\ -\left(\frac{a}{r}\right)j_n(ka)e^{ik(r-a)} \pm O\left[\left(\frac{a}{r}\right)^2\right],$$

$$2)\ i\left(\frac{1}{kr}\right)\left[\frac{d}{d(kr)}\,[krj_n(kr)]\right]_{r=a} e^{ik(r-a)} \pm O\left[\frac{a}{kr^2}\right],$$

$$3)\ -ikaj_n(ka)e^{ik(r-a)} \pm O\left[\frac{ka^2}{r}\right],$$

$$4)\ -\left[\frac{d}{d(kr)}\,[krj_n(kr)]\right]_{r=a} e^{ik(r-a)} \pm O\left(\frac{a}{r}\right).$$

Since the far zone fields are of interest, the first terms of the above relations are those used in the solution; hence,

$$\begin{aligned}
\overline{E}_s = {} & E_0 e^{i[k(r-a)-\omega t]} \sum_{n=1}^{\infty} (i)^n \left[\frac{2n+1}{n(n+1)}\right]\Bigg\{\left[-\left(\frac{a}{r}\right)\frac{\cos\phi}{\sin\theta} P_n'(\cos\theta)j_n(ka)\hat{\theta} + \left(\frac{a}{r}\right)\sin\phi\,\frac{dP_n'(\cos\theta)}{d\theta}\,j_n(ka)\hat{\phi}\right] \\
& - i\left[i\,\frac{n(n+1)}{(kr)^2}\cos\phi P_n'(\cos\theta)j_n(ka)\hat{r} - \frac{\cos\phi}{kr}\,\frac{dP_n'(\cos\theta)}{d\theta}\left[\frac{d}{d(kr)}\,[krj_n(kr)]\right]_{r=a}\hat{\theta}\right. \\
& \left. + \frac{\sin\phi}{kr\sin\theta}\,P_n'(\cos\theta)\left[\frac{d}{d(kr)}\,[krj_n(kr)]\right]_{r=a}\hat{\phi}\right]\Bigg\},
\end{aligned} \tag{19}$$

$$\begin{aligned}
\overline{H}_s = {} & -\frac{kE_0}{\omega\mu}\,e^{i[k(r-a)-\omega t]} \sum_{n=1}^{\infty} (i)^n \left[\frac{2n+1}{n(n+1)}\right]\Bigg\{\left[-i\,\frac{\sin\phi}{(kr)\sin\theta}\,P_n'(\cos\theta)\left[\frac{d}{d(kr)}\,[krj_n(kr)]\right]_{r=a}\hat{\theta}\right. \\
& \left. - i\,\frac{\cos\phi}{kr}\,\frac{dP_n'(\cos\theta)}{d\theta}\left[\frac{d}{d(kr)}\,[krj_n(kr)]\right]_{r=a}\hat{\phi}\right] + i\left[\frac{n(n+1)}{kr}\left(\frac{a}{r}\right)\sin\phi P_n'(\cos\theta)j_n(ka)\hat{r}\right. \\
& \left. - i\left(\frac{a}{r}\right)\sin\phi\,\frac{dP_n'(\cos\theta)}{d\theta}\,j_n(ka)\hat{\theta} - i\left(\frac{a}{r}\right)\frac{\cos\phi}{\sin\theta}\,P_n'(\cos\theta)j_n(ka)\hat{\phi}\right]\Bigg].
\end{aligned} \tag{20}$$

Collecting terms of the various coordinates

$$\begin{aligned}
\overline{E}_s = {} & E_0\left(\frac{a}{r}\right)e^{i[k(r-a)-\omega t]}\Bigg\{\sum_{n=1}^{\infty}(i)^n(2n+1)\left(\frac{1}{kr}\right)\frac{\cos\phi}{ka}\,P_n'(\cos\theta)j_n(ka)\hat{r} \\
& - \sum_{n=1}^{\infty}(i)^n\left[\frac{2n+1}{n(n+1)}\right]\left[\frac{\cos\phi}{\sin\theta}\,P_n'(\cos\theta)\,j_n(ka) - i\,\frac{\cos\phi}{ka}\,\frac{dP_n'(\cos\theta)}{d\theta}\left[\frac{d}{d(kr)}\,[krj_n(kr)]\right]_{r=a}\right]\hat{\theta} \\
& + \sum_{n=1}^{\infty}(i)^n\left[\frac{2n+1}{n(n+1)}\right]\left[\sin\phi\,\frac{dP_n'(\cos\theta)}{d\theta}\,j_n(ka) - i\,\frac{\sin\theta}{ka\sin\theta}\,P_n'(\cos\theta)\left(\frac{d}{d(kr)}\,[krj_n(kr)]\right)_{r=a}\right]\hat{\phi}\Bigg\},
\end{aligned} \tag{21}$$

$$\begin{aligned}
H_s = {} & \frac{kE_0}{\omega\mu}\left(\frac{a}{r}\right)e^{i[k(r-a)-\omega t]}\Bigg\{\sum_{n=1}^{\infty}(i)^n(2n+1)\left(\frac{1}{kr}\right)\frac{\sin\phi}{ka}\,P_n'(\cos\theta)j_n(ka)\hat{r} \\
& - \sum_{n=1}^{\infty}(i)^n\left[\frac{2n+1}{n(n+1)}\right]\left[\sin\phi\,\frac{dP_n'(\cos\theta)}{d\theta}\,j_n(ka) + i\,\frac{\sin\phi}{ka\sin\theta}\,P_n'(\cos\theta)\left[\frac{d}{d(kr)}\,[krj_n(kr)]\right]_{r=a}\right]\hat{\theta} \\
& + \sum_{n=1}^{\infty}(i)^n\left[\frac{2n+1}{n(n+1)}\right]\left[\frac{\cos\phi}{\sin\theta}\,P_n'(\cos\theta)j_n(ka) - i\,\frac{\cos\phi}{ka}\,\frac{dP_n'(\cos\theta)}{d\theta}\left[\frac{d}{d(kr)}\,[krj_n(kr)]\right]_{r=a}\right]\hat{\phi}\Bigg\}.
\end{aligned} \tag{22}$$

The series that comprise (21) and (22) can be identified as those of the type used to set up the incident fields[2] or identified by a technique described in a recent article;[6] hence (7) and (8) have the form

$$\overline{E}_s = \frac{a}{r} E_0 e^{i[k(r-a)-\omega t]} \left\{ -\left(\frac{1}{kr}\right) \sin\theta\cos\phi\hat{r} \right.$$

$$\left. - \cos\theta\cos\phi\hat{\theta} + \sin\phi\hat{\phi} \right\} e^{ika\cos\theta},$$

$$\overline{H}_s = \frac{a}{r} \frac{kE_0}{\omega\mu} e^{i[k(r-a)-\omega t]} \left\{ -\left(\frac{1}{kr}\right) \sin\theta\sin\phi\hat{r} \right.$$

$$\left. - \sin\phi\hat{\theta} - \cos\theta\cos\phi\hat{\phi} \right\} e^{ika\cos\theta}.$$

B. *The Poynting Vector*

Since the radial component of the far zone fields was neglected, the total Poynting vector has the following form:

$$\overline{S}_s = \tfrac{1}{2} \operatorname{Re} E_\theta H_\phi^* - E_\phi H_\theta^*]\hat{r}.$$

For the fields calculated in *A* of the Appendix,

$$\overline{S}_s = \left(\frac{a}{r}\right)^2 \frac{kE_0}{2\omega\mu} [(\sin\theta\cos\phi)^2 + (\sin\phi)^2]\hat{r},$$

$$\overline{S}_s = \left(\frac{a}{r}\right)^2 P_0[1 - \sin^2\theta\cos^2\phi]\hat{r}.$$

C. *Equivalent Gain of the Sphere*

The equivalent gain of the sphere over an isotropic scatterer was computed from the pattern volume. For linear polarization,

$$V_L = 8 \int_0^{\pi/2} \int_0^{\pi/2} \int_0^{\cos^2\phi} r^2 \cos\phi \, dr \, d\phi \, d\theta,$$

$$V_L = \frac{64\pi}{105}$$

from which the radius of the equivalent sphere is computed to be 0.77; hence,

$$G_L = \frac{1}{0.77} = 1.30.$$

For the case of circular polarization,

$$V_c = 8 \int_0^{\pi/2} \int_0^{\pi/2} \int_0^{1/2(1+\cos^2\theta)} r^2 \sin\theta \, dr \, d\theta \, d\phi,$$

$$V_c = \frac{16\pi}{35}$$

and the radius of the equivalent sphere was computed to be 0.70; hence

$$G_c = \frac{1}{0.7} = 1.43.$$

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[6] T. Vea, "Generating functions and the summation of infinite series," to be published in PROC. IRE.

Project SCORE*

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Summary—This paper is designed to provide a review and summary of the over-all program of development, construction and operation by the U. S. Army Signal Research and Development Laboratory of the first satellite communication system placed in orbit on December 18, 1958. This effort was part of Project SCORE (Signal Communication by Orbiting Relay Experiment) directed by ARPA. Basically, Project SCORE consisted of designing, constructing, and conducting an actual flight experiment of a delayed repeater type satellite package using an actual stripped down Atlas missile as the satellite container. The major points to be covered are summarized in the following paragraphs.

A brief historical résumé of the project will cover the preliminary discussions regarding the feasibility of orbiting an Atlas ICBM; the vehicle and weight limitation affecting preliminary system design; mechanical and electrical test problems and ground station installation and on-site training.

The system description will cover orbit data; ground station site location and control; airborne equipment components such as antennas, temperature control and communication electronics; general considerations of system design and design problems; ground station equipment including recording and test equipment and associated ground communication equipment.

The system operation portion of the paper will cover a brief summary of the launch into orbit and actual life of the communications system; actual operating procedures used to achieve maximum benefits from the experiment; a summary of test data obtained with chart and graph presentations; a discussion of test results and the factors affecting the evaluation of test results; and selective comments on equipment reliability.

The final part of the paper will contain conclusions to be made from the equipment and the impact of these conclusions on the planning for future communications satellite systems.

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* Original manuscript received by the IRE, December 2, 1959.

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STARTING with the development of radio communication equipment suitable for operational use in the VHF and UHF frequencies, system designers and operating personnel alike have been concerned with the problems imposed by line-of-site propagation at these frequencies. Equipment operating on even higher frequencies with corresponding greater communication channel capacity is being developed and placed in operational status. However, no reliable and economic means of providing single-link, wide-band communication facilities over intracontinental and intercontinental distances yet exists.

To fill this communication gap, extensive networks of coaxial line and microwave radio relay systems have been developed and installed in the continental United States during the past decade. The logistics problems attendant upon the installation and maintenance of these systems in the confines of the United States are tremendous, even with a relatively favorable environment. Applying the same techniques to a fluid military situation aggravates the difficulties to produce an almost impossible situation. The economics of the problem of providing multichannel communication under these conditions are such that only the pressure of military necessity justifies the cost. Even in commercial practice, the installation of radio relay and coaxial cable facilities is limited to the land masses of the eastern and western hemispheres. There are no means available to cross the reaches of the Atlantic and Pacific Oceans with economically sound and reliable radio relay or coaxial facilities capable of transmitting, for example, real time television program material.

Many schemes have been proposed, such as circling aircraft, blimps or dirigibles, land stations installed on the islands which dot the subarctic borders of the Atlantic and Pacific Oceans, anchored platforms and cables with sealed-in repeaters. Each of these, except the last, in one form or another has developed flaws, either logistic or technical, which makes them extremely unattractive, if not impossible. The last has been accomplished in recent years for multichannel telephone and slowed-down television; however, it is quite vulnerable to earthquakes, tides and Soviet trawlers.

With the successful launching of man-made satellites, their possibilities as elements in world-wide transmission systems were the subject of considerable speculation. A satellite, quite obviously, has many attractions as a vehicle for an unattended radio relay repeater. It requires no fuel to maintain it on its appointed course. Once in orbit, its position can be predicted with great accuracy and by selection of orbits, with no more than two relay points, any two locations on earth can be linked.

Attractive as these possibilities are for commercial communication systems, they become almost irresistible for world-wide military networks. At the present time the satellite station is practically impossible to intercept. It requires no friendly real estate to house equipment and, powered either by atomic energy or solar radiation, needs no logistic support. Operating as a delayed repeater, a satellite link could give a military system a considerable antijamming advantage.

Naturally, there are some disadvantages. The electronic equipment must be rugged enough to withstand the hazards of launching, one hundred per cent reliable for a time at least sufficient to amortize its initial cost and launching expenses, and capable of withstanding the extreme conditions existing in outer space. None of these appear to be insurmountable at the present time.

It was in an environment of such considerations that the Advanced Research Projects Agency, jointly with the Army and the Air Force, undertook Project SCORE. The object of this project was to place in orbit an eighty-foot long Atlas missile and to use this as a platform for a communication system capable of spanning intercontinental distances. The ultimate goal was to demonstrate dramatically the feasibility of such a system and to explore some of the technical and operational problems that would attend a military satellite communication system. The communications portion of the project was approved and assigned to the U. S. Army Signal Research and Development Laboratory late in July, 1958. The launching date was set for early November, 1958, which required that system and equipment design and installation in the vehicles had to be completed by the middle of October to avoid interference with prelaunch checkouts. Ground stations were required to be installed and operating crews trained by November 1, 1958. This was admittedly an extremely short deadline within which to accomplish project SCORE.

The plans were to install two complete communication packages in the Atlas missile. These each would include a receiver, transmitter, control unit, battery supply tape recorder, and tracking beacon. Ground equipments installed in standard army type V-51 vans with associated support vehicles were to be located at Fort MacArthur, Calif., Fort Huachuca, Ariz., Fort Sam Houston, Tex., and Fort Stewart, Ga. This equipment would include a Quad helix tracking antenna mounted on searchlight base, receiving, transmitting and control equipment along with appropriate recording, telephone and teletype terminal equipment. In addition, the California station would have a direction finder to assist in initial pickup and tracking of the satellite. All ground stations were to be linked by both telephone and HF radio to a system control center at the Deal Area of the Signal Corps Laboratory in New Jersey.

Preliminary calculations indicated that an elliptical orbit with an apogee of between 500 and 800 miles and a perigee of approximately 100 miles might be achieved. The launching was to be from the Atlantic Missile Range at Cape Canaveral with an inclined orbit of 30°. Fig. 1 illustrates the orbit geometry and the location of the four operating ground stations.

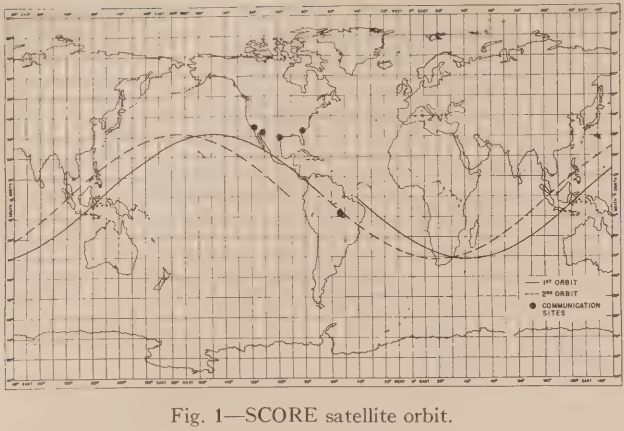

Fig. 1—SCORE satellite orbit.

The design of the system was based on providing two modes of operation; as a delayed repeater and as a real time active satellite repeater. In the delayed repeater mode, the satellite, upon reception of a suitable command signal from a ground station would record information transmitted to it. Upon reception of a different command signal, it would then transmit back to the ground station originating the command the information previously stored. Within the limitation of the storage capacity in the satellite, the information transmission rate, and hence the bandwidth, of the system and the time in view over each of the ground stations, a delayed repeater can provide intercontinental "store and forward" message transmission service.

The second mode of operation, that of a real time repeater, was obtained by the use of yet another command signal which activated the satellite as a radio relay repeater station with the recording mechanism bypassed. Here, the transmission capability of the system is limited by the time the satellite is in view of both stations simultaneously and the system bandwidth. The locations of the four ground stations were based, in part, on providing station separations which would permit testing of the real time capability over varying distances.

The system parameters which were incorporated in the satellite and ground equipments are indicated in Table I. VHF frequencies were used to minimize the effects of cosmic noise and ionospheric propagation while still permitting the use of sensitive, transistorized receiving equipment in the satellite. The power levels employed were consistent with what could be obtained in the time frame of the program. The bandwidths selected were the minimum consistent with frequency stability, Doppler frequency variations, maximum audio frequency and carrier frequency deviation. Allowance was made for ±4-kc variations caused by Doppler shift and ±5 kc for the first-order sidebands of the modulation with the deviation ratio limited to 1.0 at 5 kc. The frequency stability of the satellite components was within ±0.005 per cent. Consistent with the expected apogee of 500 to 800 miles, the system design was based on 1000-miles slant range. Power balance calculations using this value resulted in the fade margins indicated, including allowances for miscellaneous losses in transmission lines, duplexers, filters and ring isolators.

TABLE I

SCORE System Parameters

	Satellite	Ground
Transmit Frequency	132 mc	150 mc
Receive Frequency	150 mc	132 mc
RF Power Output	8 watts	1000 watts
Noise Figure	10 db	6 db
IF Bandwidth	40 kc	40 kc
Audio Bandwidth	0.3–5.0 kc	0.3–5.0 kc
Antenna Gain	0 db	16 db @150 mc
FM Threshold	10 db	10 db
Fade Margin	39 db	19 db

The satellite elements of the system were designed with due consideration for simplicity, the capability to withstand the mechanical environment during powered flight, an adequate thermal design to maintain the electronic components within reasonable temperature limits while in orbit, and redundancy to improve the likelihood of a successful communications experiment. Two complete systems, using slightly different radio frequencies, were installed in the Atlas missile to provide the redundant feature. Table II summarizes the size, weight and power drain for the items comprising the over-all satellite system.

TABLE II

SCORE Component Characteristics

Components	Weight (Pounds)	Size (Cubic Inches)	Power Drain (Watts)
Receiver	0.75	39	0.24
Transmitter	2.5	101	51.3
Beacon	1.0	27	0.36
Control Unit	0.75	37	3.0*
Recorder	3.25	99	1.4
DC-DC Converter	1.0	19.2	—
Battery	21.0	175	—
Mount and Hardware	14.5	—	—
Antenna System	54.0	—	—

* Relay mode only.

The major design areas for the satellite system can be broken down into the following areas which are described below.

The major elements of each of the satellite systems are shown in Fig. 2 as well as the over-all configuration. Fig. 3 indicates the interconnection between the major elements. As shown in Fig. 3, separate antennas were used for the communication receiver and transmitter with a beacon transmitter diplexed with the higher powered communication transmitter.

The communications receiver was a double superheterodyne frequency-modulated all-transistor receiver, a modified version of a commercial type. Considerable improvement in sensitivity was attained by the use of selected transistors in an RF amplifier stage which was included; noise figures in the 10-db to 13-db range were

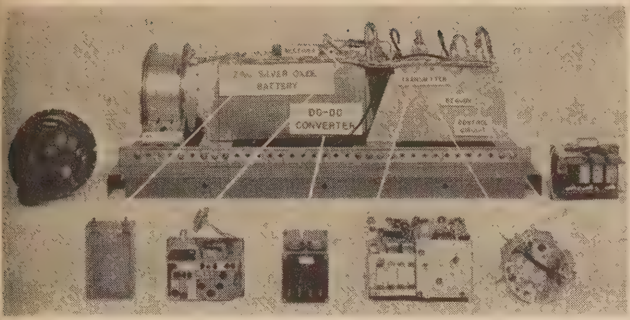

Fig. 2—SCORE system satellite components.

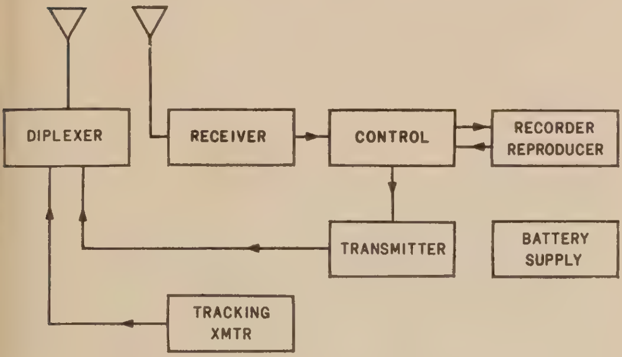

Fig. 3—SCORE satellite interconnection diagram.

realized. Although the receiver power drain was only 0.24 watt, it represented a considerable expenditure of energy over long periods of time if it were permitted to operate continuously. To conserve the limited battery supply, a battery saver circuit was included in the receiver design which, during standby periods between interrogations, turned the receiver on for a period of $\frac{1}{4}$ second each $2\frac{1}{2}$-second period, thereby reducing the power requirement by a factor of 10. This substantial saving in power drain was thereby achieved without introducing appreciable delay in detecting command signals.

The transmitter used vacuum tubes throughout and provided 8-watts frequency-modulated power output. The circuitry used was conventional, in keeping with the urgency of the development cycle. Plate and screen voltages for the transmitter were obtained from a transistorized dc to dc converter operating from the battery power supply. A relatively high conversion efficiency of 82 per cent was obtained with the converter operating with a ripple frequency of 2500 cps.

The control unit consisted of transistorized switching circuits activated by special telemetry type notch filters at frequencies of 3000, 3900 and 5400 cps. These tones corresponded to the record, playback and radio relay modes, respectively, and caused the appropriate connections to be made between the transmitter, receiver and tape recorder. The 5400-cps tone had an alternate capability of disabling the record and playback modes and caused the system to revert to a standby status. This was included to provide a measure of control of the satellite system by the ground stations in the event that the automatic cycling sequence incorporated in the satellite design might fail.

The recorder-reproducer was a miniature type originally designed and built at the Signal Corps Laboratory for a meteorological satellite, but modified for application to the SCORE project. The electronic circuitry including erase, playback and record functions was completely transistorized; the tape drive mechanism was pressurized for reliable operation of the dc motor in the space environment. An endless loop of 75 feet of 1-mil mylar tape, operating with a tape speed of $3\frac{1}{4}$ inches per second (ips) provided 4 minutes of recording or playback time with a 300- to 5000-cps bandwidth. A $\frac{1}{2}$-inch metallic coated section of the tape which momentarily completed an electrical circuit indicated the stopping point on the endless loop. This contact caused the control unit to revert automatically to a standby status at the completion of a record or playback cycle.

The nominal 108-mc tracking beacon used was a modified version of the transistorized type used in Explorer I. One channel of FM-AM telemetry was included in the design to indicate temperature variations in either the missile pod cover or one of the electronic packages. Output power was a continuous 30 milliwatts.

Based on the expected life of the satellite of 21 days, a chemical battery system rather than a costlier and heavier solar cell and rechargeable nickel cadmium battery system was used. Zinc-silver oxide batteries were chosen because of their high capacity (watt hours per pound) and ability to handle occasional peak loads, such as the communication transmitter.

The antennas employed consisted of two simple slot antennas for reception and two for transmission, a receiving and a transmitting antenna being located on each instrumentation pod of the missile. A typical slot antenna is shown in Fig. 4 which was fabricated from fiberglass honeycomb sandwich material with the conducting surfaces applied by means of an aluminum metal spray process.

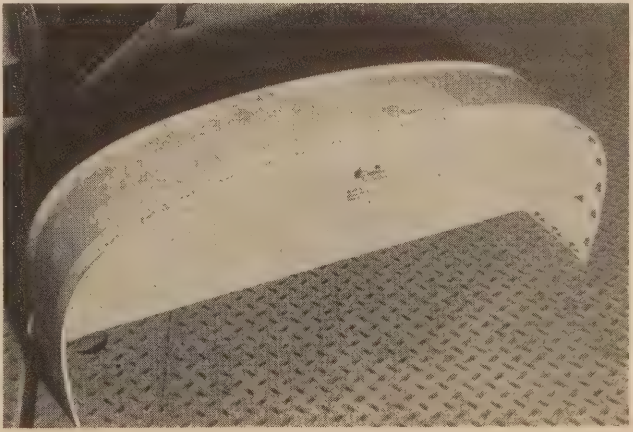

Fig. 4—Slot antenna used with SCORE satellite.

Fig. 5 indicates the manner in which the various components were interconnected; band-pass filters and ring couplers being used to isolate the effects of like units from each other while still providing a low-pass path connection to the antennas located on opposite pods of the missile. The separate transmitting and receiving antennas provided the additional decoupling necessary to eliminate desensitization of the receiving equipment.

The antenna radiation pattern attained was essentially that of a multiwavelength doublet with the attendant deep nulls. The effect of the missile tumbling in its orbital flight was to introduce fades of up to 15 db in the transmission path. The fade margins indicated in Table I were made as large as possible to overcome this effect.

Fig. 6 indicates the over-all configuration of each system mounted on rails on the Atlas missile. The electronic components were coated, where circuit configurations permitted, with a conformal resin coating. All of the major assemblies were further encapsulated in an isocyanate foam, and poured into place within lightweight, polished aluminum canisters. Printed wiring was further used in most units. The finally assembled units, in their canisters, were attached to the mounting rails through isocyanate foam and laminated fiberglass mounts, with the exception of the recorder where solid Kel-F plastic mounts were used. These mounts provided a measure of vibration isolation but, more important, thermally isolated the electronic equipment from the skin of the missile. The over-all configuration withstood accelerations of 10 g from 20 to 2000 cps and $\frac{1}{4}$-inch excursions from 5 to 20 cps.

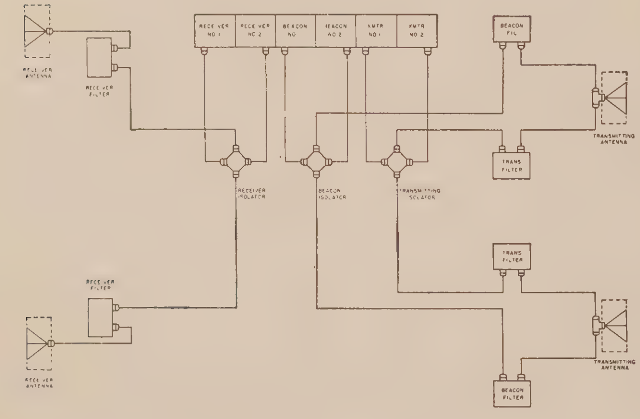
RECEIVER NO 1
RECEIVER NO 2
BEACON NO
BEACON NO 2
XMTR NO 1
XMTR NO 2
BEACON FIL
RECEIVER ANTENNA
RECEIVER FILTER
TRANSMITTING ANTENNA
TRANS FILTER
RECEIVER ISOLATOR
BEACON ISOLATOR
TRANSMITTING ISOLATOR
TRANS FILTER
RECEIVER FILTER
TRANSMITTING ANTENNA
RECEIVER ANTENNA
BEACON FILTER

Fig. 5—SCORE antenna connection diagram.

The thermal design presented unique problems because of the difficulty in providing an adequate thermal environment in the vicinity of the electronic components. A range of +40°F to +120°F was the largest useable, if system performance were to be met. The approach finally decided upon was to use highly polished surfaces on the communication components while the surface of the metallic pod covers were iridited. This was expected to produce a mean temperature of approximately 90°F within the individual packages. The expected low duty cycle of the communication transmitter was not expected to cause an appreciable temperature rise within its canister. Since the temperature compensation problem was not straightforward and was severely limited by payload and development time considerations, the results obtained were not unexpected.

The ground stations were designed to be operated from transportable vans and trucks and included certain minimum requirements. In addition to the radio terminal equipment, including transmitters, receivers, telegraph and telephone terminal equipment, as shown in Fig. 7, it was necessary to provide means for tracking the orbiting satellite with a high gain antenna, recording pertinent signal level and communication data, and automatically sequencing the ground equipment for either transmission or reception with the satellite.

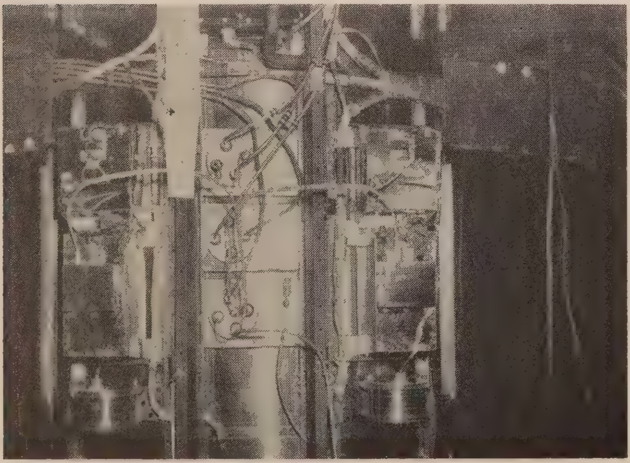

Fig. 6—SCORE satellite components mounted on Atlas 10B missile.

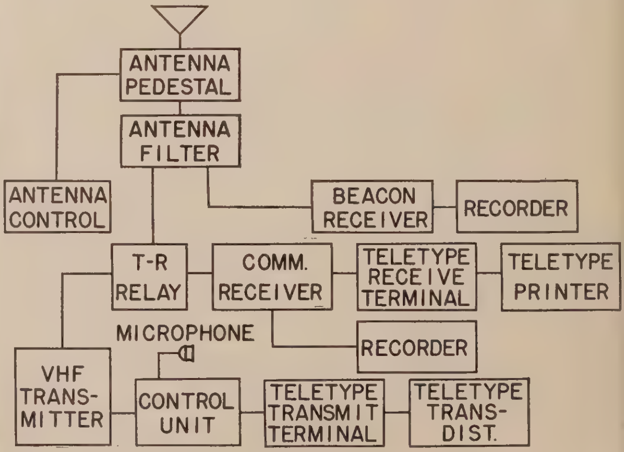
ANTENNA PEDESTAL
ANTENNA FILTER
ANTENNA CONTROL
BEACON RECEIVER
RECORDER
T-R RELAY
COMM. RECEIVER
TELETYPE RECEIVE TERMINAL
TELETYPE PRINTER
MICROPHONE
RECORDER
VHF TRANS-MITTER
CONTROL UNIT
TELETYPE TRANSMIT TERMINAL
TELETYPE TRANS-DIST.

Fig. 7—SCORE ground station interconnection diagram.

The VHF radio terminals were modified commercial types with characteristics as listed in Table I. Backups were provided for all major items in the communications chain with both a 250-watt and a 1000-watt transmitter, for example. These units occupy the center of Fig. 8, an interior view of the operations van. The teletype multiplex equipment was capable of either seven-channel, frequency division multiplex operation or single-channel, 850-cps frequency shift operation. Standard military teletype sets were used for receiving, transmitting and preparing messages on perforated tape.

The control unit shown in Fig. 9 not only originated the command tones transmitted to the satellite, but also automatically accomplished the switching of the receivers, transmitters, teletype machines and other equipment in the proper sequence. At the operators' position, a patch panel was also provided which permitted changing the operating sequence or type of service at a single location.

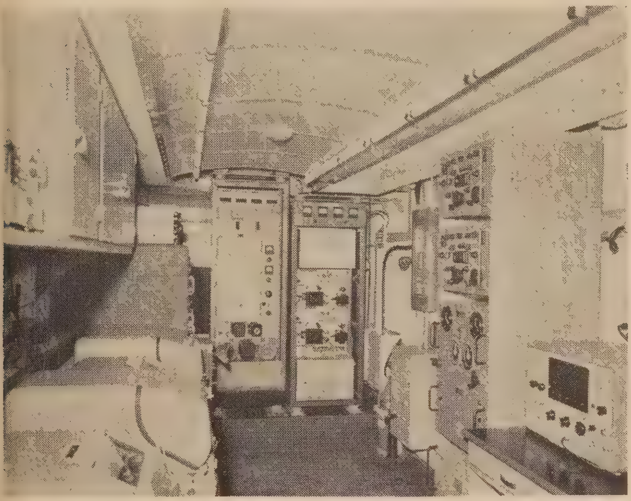
Fig. 8—Interior view of SCORE ground station operations van.

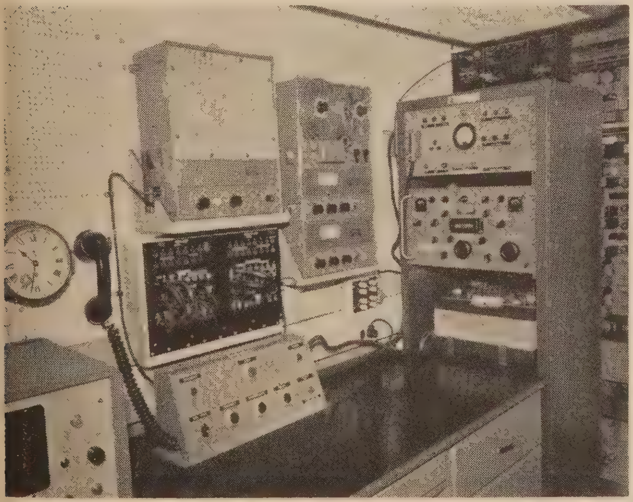
Fig. 9—Operator's console in SCORE ground station.

Recording devices, including magnetic tape recorders and pen recorders, were also supplied to provide permanent records of such things as signal level variations and communication traffic.

The antenna system used (see Fig. 10) was a circularly polarized, quad-helices array with a screen reflector mounted on a modified searchlight pedestal. The gain provided varied from 10 db at the 108-mc tracking frequency to 16 db at the 150-mc communication frequency. Coverage of 360° in azimuth and 90° in elevation was controlled at all but the California station by an operator maximizing the 108-mc signal reception with the antenna positioning controls located near the tracking receivers. At the California station, the azimuth control was slaved to the alidade of an experimental direction-finding equipment while the elevation control was manually varied. Even this partial automation resulted in a marked improvement in tracking accuracy and system performance.

The successful launching of the Atlas missile 10B on December 18, 1958 and the subsequent operation of the communication system installed therein almost instantly assumed importance as an achievement of national and international significance. This fact interfered with the conduct of the technical portions of the project to such an extent that the orderly collection and analysis of data were somewhat neglected for the first week of operation. Therefore, some important clues that might have explained some discrepancies later observed were lost. Qualitatively, the practical operation of a satellite radio relay system capable of spanning intercontinental distances either in real or delayed time was demonstrated conclusively until battery failure occurred on December 30, 1958. For example, communication traffic, both voice, single-channel teletype and multichannel teletype, was carried on a delayed repeater basis in many successive orbits around the earth and was

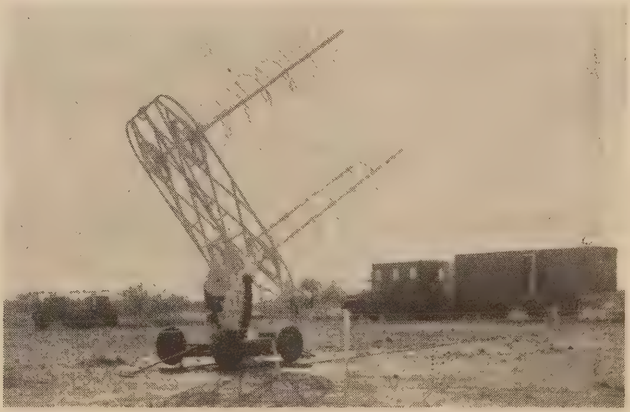
Fig. 10—Exterior view of SCORE ground station showing tracking and communication antenna.

made available individually to the four ground stations at their command.

The ground stations interrogated, received and recorded, for simulated distribution, a total of 78 messages for a total of 5 hours, 12 minutes communication time. Of these, 28 separate messages had been placed in the satellite recorder by ground stations. The remainder were multiple interrogations of previously recorded material. A total of 1 hour and 52 minutes operation of the satellite in the recording mode was involved for these 28 loadings. Eleven real time relays from California to Georgia, a distance of over 3000 miles, were successfully made for a total of 43 minutes of satellite operation. In several instances, unauthorized fortuitous recordings from unidentified stations, with apparently random distribution in the Eastern hemisphere, were received during interrogations by both the California and Georgia stations. In all probability, many fortuitous interrogations of the satellite also were made but there were no means of determining the number of these. This does indicate that a simple tone keyed command system is highly inadequate for future satellite applications.

One set of equipment failed because the tape recorder became inoperative on the first orbit allowing the transmitter to operate continuously and discharge the battery. The other equipment operated exactly as planned other than with somewhat smaller fade margins than had been expected. This satisfactory operation was obtained in spite of the fact that internal temperatures appeared to rise to over 20°F higher than the maximum temperature of 120°F for which the equipment was designed.

This system, which was assembled in record time, demonstrated a world-wide single-voice channel communication capability, over intercontinental distances, in real time, and to and from any point on earth by delayed (store and forward) repeater techniques.

There is no insurmountable barrier to the expansion of the principles demonstrated by this project to the dimensions necessary for an economically practical, world-wide communication system. The communication equipments developments required are well within the state of the art, namely, wide-band transmitters and receivers, a recording facility of complementary capacity and a secure command control system, all capable of providing unattended operation for a year or more by using redundancy and other techniques. It is beyond the purpose of this paper to analyze the bandwidth and time dimensions necessary for economic feasibility, but, in all likelihood, the electronic equipment could be available in about the same time frame as the rocket power necessary to place such a satellite into a proper orbit.

A Broad-Band Spherical Satellite Antenna[*]

HENRY B. RIBLET[†], SENIOR MEMBER, IRE

Summary—**The design criteria and results of the design of a broad-band spherical antenna are discussed. The parameters of design and their effect on radiation patterns are briefly investigated. The particular antenna was developed from an equiangular spiral slot plotted on a plane and then projected on the surface of a sphere. Attention is given to problems of isolation and matching when the antenna is used for multifrequency operation. The particular antenna discussed is being used in the TRANSIT satellite program.**

INTRODUCTION

THE need for a broad-band antenna, covering a frequency of at least four to one, is dictated by the use of the four harmonically related frequencies 54, 108, 162, and 216 megacycles in the TRANSIT satellite. These four frequencies are used to obtain data pertaining to the ionosphere refraction observed during Doppler measurements. In addition to the wide range of frequencies, the desirability of radiation patterns as near isotropic as possible led to the design of the equiangular spiral slot antennas projected onto the surface of a sphere. This antenna provides radiation patterns which have nulls no deeper than 10–15 db, at any angle around the sphere, except the one produced by cross polarization at the equator.

ANTENNA CONFIGURATION

Unless the satellite is stabilized with respect to the earth, the variations in attitude caused by spin, tumbling, and other changes in space orientation will require the radiation pattern to have a uniform field intensity in all directions, *i.e.*, isotropic, in order to minimize the signal strength variations at the receiver. Because it is next to impossible to obtain a practical isotropic antenna, the specifications for the TRANSIT satellite antenna call for peak-to-peak field intensity variations of not more than 10 db within the spherical coordinate system for all four frequencies. Other requirements make the use of protruding dipole elements mechanically difficult. With few exceptions, the flush-mounted spiral slot satisfied these specifications.

The spherical shape of the TRANSIT satellite was chosen initially to obtain thermal balance regardless of attitude; however, the same property of the sphere, having only one linear dimension, the circumference, aids greatly in obtaining a nearly uniform radiation pattern. To fulfill the broad-band frequency requirement, the properties of an equiangular (logarithmic) spiral slot was utilized. The shape and dimensions of a spiral slot antenna are specified entirely by angles. When this is true, its electrical dimension is constant with wavelength; hence, its performance is "broad-band." These broad-band characteristics give uniform beam widths and impedances over frequency ranges up to 10 to 1. Other familiar examples of broad-band antennas are the biconical horn and the disk-cone antenna.

As shown in Fig. 1, the equiangular (*i.e.*, logarithmic) spiral has the property that the angle A between the tangent to the curve and the radius vector at any point on the curve is a constant. Angle A must be larger than 90° to qualify as a spiral. The spiral can be defined by

$$\rho = Ke^{a\theta}.$$

This equation describes the curve that forms one edge of the spiral slot or the conductor in the case of its complementary form, a conducting spiral element. The other edge of the spiral can then be defined by

$$\rho' = Ke^{a(\theta-\alpha)},$$

where the angle α is lag angle between equal radius vectors as shown in Fig. 2.

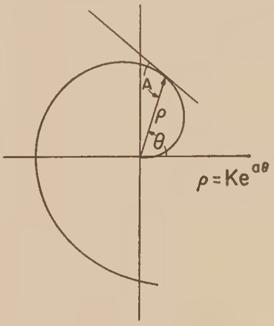

Fig. 1—Construction of the equiangular spiral.

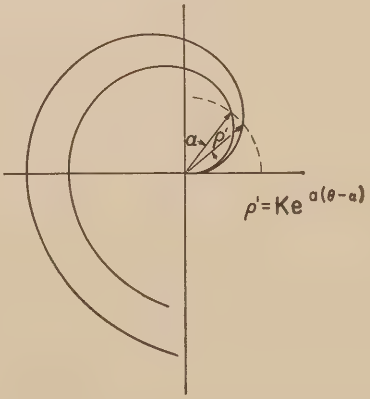

Fig. 2—Construction of two spirals with a difference angle α.

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[*] Original manuscript received by the IRE, November 23, 1959. This work was supported by the Navy, Bureau of Ordnance, under Contract NOrd-7386.

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The slot width is the distance between ρ and ρ' at equal angles of θ. A double spiral slot can be constructed by plotting two spirals 180° with respect to each other as shown in Fig. 3.

The double spiral slot was projected on the surface of each hemisphere to complete the antenna as shown in Fig. 4.

RADIATION PATTERNS

The nearly uniform radiation patterns are obtained by controlling the current and phase distributions over the entire surface of the sphere. With separate balanced spiral slots on each hemisphere one has a few parameters which can be adjusted to achieve optimum performance. These parameters are the screw sense of the spiral, the feed point phase, and the rotational position of one hemisphere with respect to the other. There are several combinations of these parameters which will produce varied radiation patterns.

In the case of the satellite, the antenna must be designed to give as near a uniform radiation field as possible. It is necessary, therefore, to adjust these parameters so that in any plane through the poles of the sphere the current distribution is in phase for any set of symmetrical points. If the hemispheres are isolated by a metal conducting disk through the equator, the radiation from each hemisphere in the direction of its pole is essentially independent since the other hemisphere is completely shadowed. Now as the point of radiation moves toward the equator, radiation components from the other hemisphere become increasingly contributing, until the field from the equator has equal components of radiation from each hemisphere. If these components can be made to be in phase for all longitudinal angles around the equator, they will add to fill in the null of revolution to the maximum extent. Fig. 5(a) shows that for a fixed feed point phase and for spirals wound in the opposite sense, the electric field across the slot will be in phase at all points around the equator providing the two spirals are lined up in a rotational sense so that the ends and the beginning of the spirals are on the same longitudinal angle. By the same technique, Fig. 5(b) shows that for spirals wound in the same sense, the radiation will be in phase at $\phi=0$ and out of phase at $\phi=90°$.

Fig. 6 shows the evolution of the radiation patterns obtained from a spiral slot in a flat conducting sheet to those obtained from the sphere with two hemisphere cavities.

The radiation patterns from the spiral slot in the flat conducting sheet are bidirectional with essentially a complete null in the plane of the conducting sheet. When this spiral antenna is backed by a resonant cavity it becomes unidirectional with the main lobe still normal to the conducting sheet and a null in the plane of the conducting sheet.

When the spiral antenna is projected onto the hemisphere with the cavity produced by closing off the hemisphere at the equator, the radiation pattern is essentially unidirectional with null fill-in at the equator where a complete null was present in the case of the flat conducting sheet. There is a small back lobe caused by spill-over currents. When the two hemispheres are placed back to back and the proper phasing is accomplished as stated above, the side null is further filled in at the equator and the antenna becomes essentially omnidirectional, since the pattern is a figure of revolution about the polar axis.

At the higher frequencies, where the spacing of the center of radiation of each hemisphere is greater than 180°, a slight double null on each side is noticeable on account of the out-of-phase fields at some angle between the poles and the equator. These nulls are not generally very deep because of the large unbalance in contributing fields from each hemisphere.

A considerable amount of experimental testing was done to determine the total radiation field at four frequencies. Because the time scale was too short to make a detailed analysis of the theory and basic design, rather detailed experimental work was done. The efficiency of radiation was checked by comparison with a dipole radiating element and, as expected, the efficiency is a few db below that of a resonant dipole where the circumference of the sphere is less than one and one-half wavelength. However, for the frequencies, above the cutoff frequency, the gain was comparable with that of a one-half wave dipole.

The polarization of radiation from a double spiral slot antenna projected onto each hemisphere of a sphere is essentially circular from the poles and progresses through elliptical polarization to linear at the equator. The linear polarization from the equator is parallel to the polar axis. In order to produce the uniform phase distribution around the equator, the spiral on one hemisphere must be wound right hand and the other left hand as shown in Fig. 5(a). This results in right circular polarization from one hemisphere and left circular polarization from the other. This property makes the use of a circularly polarized receiving antenna impractical and, therefore, a linear polarized receiving antenna would probably yield the best results even with the cross-polarized null at the equator. Of course, polarization diversity would yield the best results. Figs. 7–10 show typical radiation patterns at each of the four frequencies for both horizontal (θ) and vertical (ϕ) polarization. Fig. 11 shows the coordinate system used in the radiation pattern measurements.

IMPEDANCE CHARACTERISTICS

The broad-band antenna also has fairly uniform impedance characteristics with frequency. Generally, the impedance will go through some sharp resonances at certain frequencies below the so-called cutoff frequency and then will exhibit fairly flat resistance and reactance above this frequency to the upper limit.

The cutoff frequency corresponds to the lowest fre-

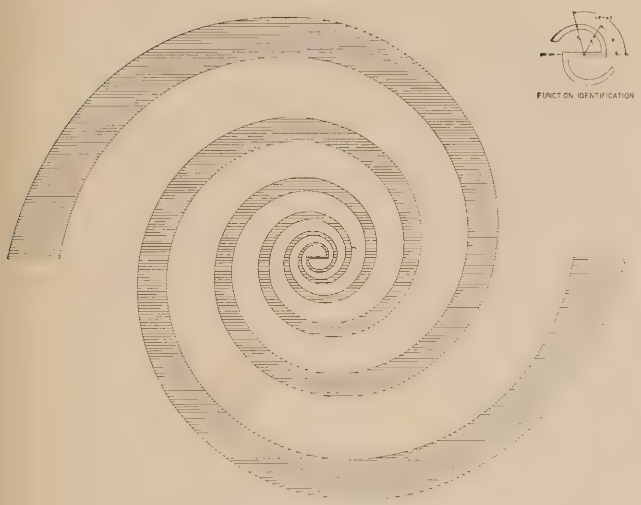

FUNCTION IDENTIFICATION

Fig. 3—Equiangular spiral slot antenna on a flat sheet.

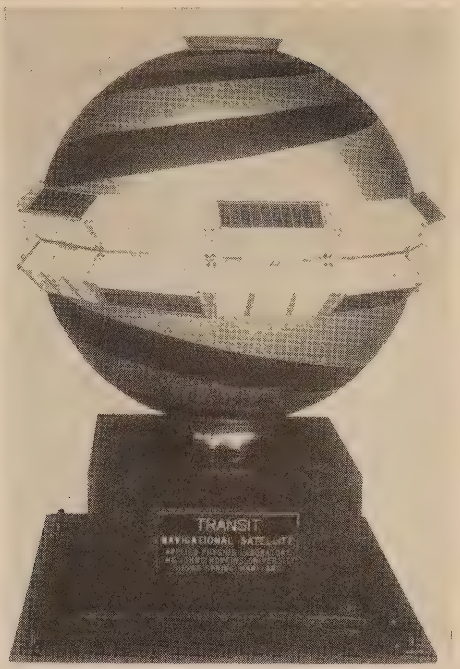
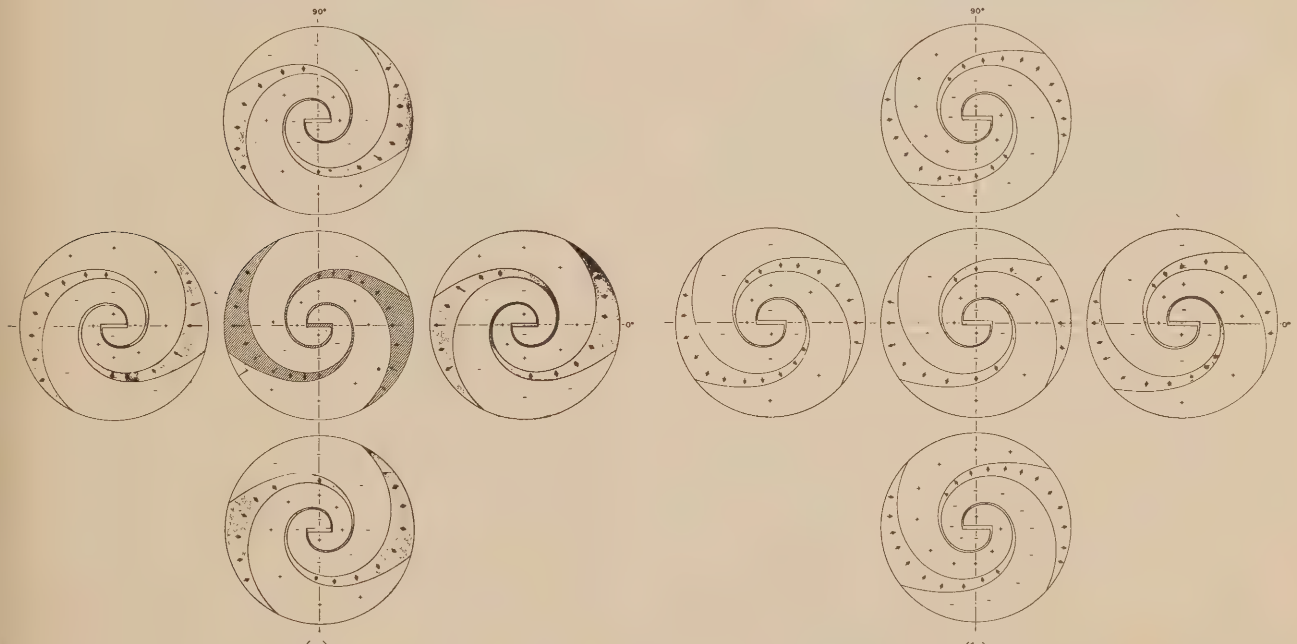

TRANSIT
NAVIGATIONAL SATELLITE

Fig. 4—TRANSIT satellite showing spiral slot antenna.



(a) (b)

Fig. 5—(a) Phasing diagrams of slot antenna clockwise and counter-clockwise spiral; (b) phasing diagrams of slot antenna two clockwise spirals.

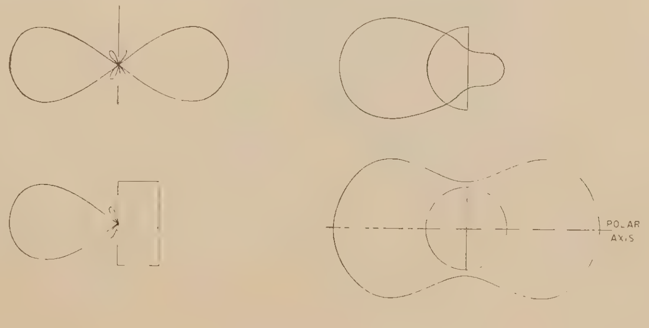


Fig. 6—Evolution of the spiral spherical antenna.

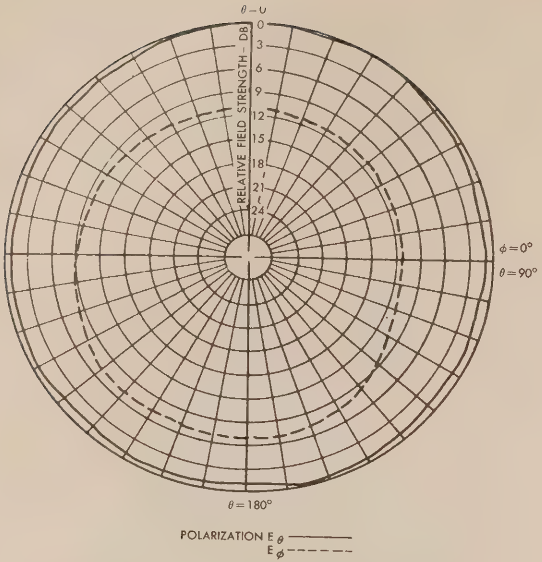


Fig. 7—Spiral antenna, frequency 54 mc.

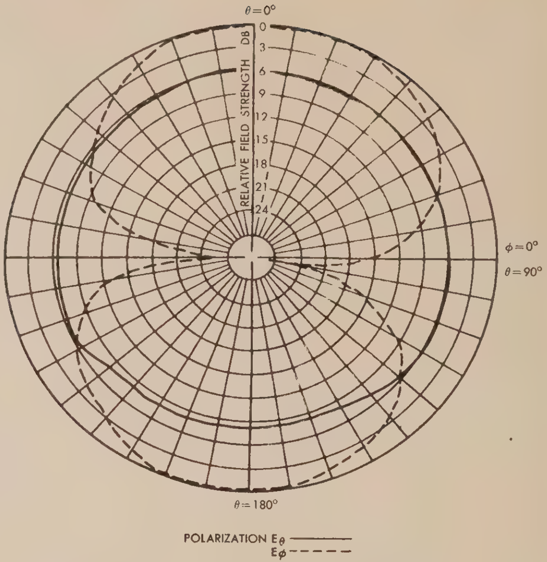


Fig. 8—Spiral antenna, frequency 108 mc.

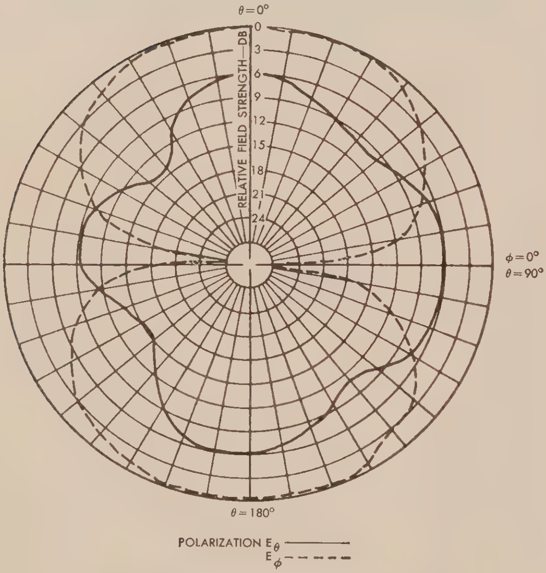


Fig. 9—Spiral antenna, frequency 162 mc.

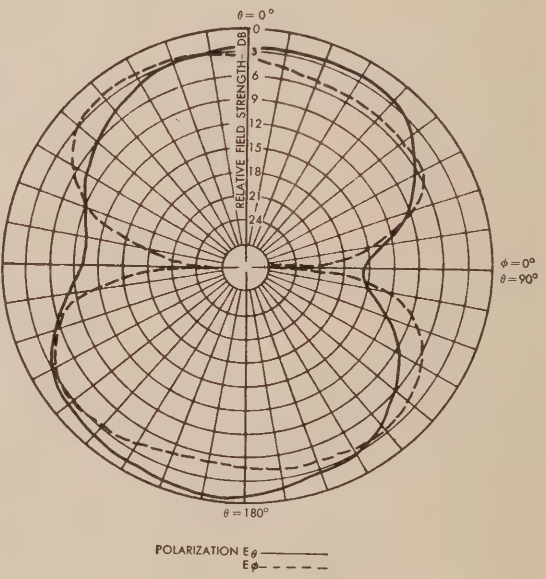


Fig. 10—Spiral antenna, frequency 216 mc.

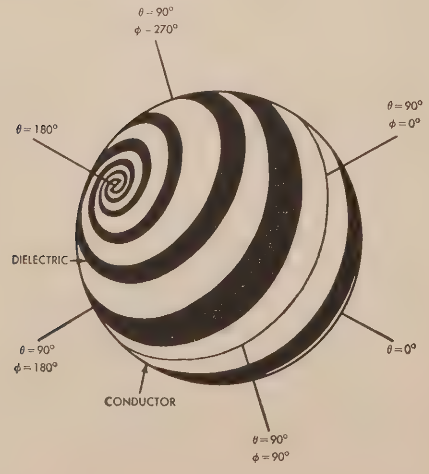

θ=90°
φ=270°
θ=180°
θ=90°
φ=0°
DIELECTRIC
θ=90°
φ=180°
θ=0°
CONDUCTOR
θ=90°
φ=90°

Fig. 11—Spherical coordinate radiation pattern reference system for satellite antenna.

quency at which the wave travelling down the slot is infinitely attenuated by the time it reaches the end. This is similar to the so-called infinite transmission line. As mentioned above, cutoff occurs at a frequency where the diameter of the spiral is approximately one-half wavelength or the circumference is about one and one-half wavelengths. For the 36-inch sphere used in the TRANSIT satellite, the cutoff frequency has a wavelength of about 2 meters or approximately 150 mc. The impedance measurements shown in Fig. 12 indicate that the cutoff frequency (that frequency at which the radiation resistance begins to flatten out) is about 135 mc.

The operation of this antenna at frequencies of 54 and 108 mc, therefore, is below the cutoff frequency, resulting in a high VSWR and lowered efficiency. However, after impedance matching, the efficiency has proven to be adequate as shown by field strength and gain measurements with respect to a one-half wave dipole.

Coupling and Matching Network

The RF feed cables are attached to the conductive coating between the slots and are carried in this manner to the feed points where the outer conductor of the coaxial line is attached to one side of the slot and the inner conductor to the other. This provides a method of feeding the balanced slot with an unbalanced feed line without the use of a balun. These RF feed cables are of equal length to provide in-phase coupling and are joined at a common *T* connector.

The use of the antenna at the four frequencies required isolation networks in the RF coupling system. After isolation, individual matching stubs are used to yield an input impedance of 50 ohms resistance.

The coupling and isolation networks for the four transmitters are constructed of coaxial cable using open quarter wave-stub techniques for notch filters. This type of filter provides approximately 30 db of isolation at each frequency. Fig. 13 shows a schematic diagram of such a coupling and isolation network. The insertion loss at each frequency is about 1.0 db. The use of filter stubs on each feed line gives some mismatch in addition to the normal VSWR caused by the antenna impedance's not being exactly equal to the characteristic impedance of the transmission line. This total mismatch is corrected to 50 ohms by the use of a separate matching stub at each frequency after the isolation filters. Thus, it affects only that frequency.

Conclusions

The antenna described in this paper has been flight tested and has given field strengths approximately equal to the measured values. The configuration used is not necessarily the most optimum and there are plans to continue the experimental work to confirm further the design for higher frequencies. No work has been done on variations of slot width for adjusting the impedance level. Radiation pattern measurements are being continued to determine the performance of other combinations of slot orientation in one hemisphere with respect to the other as well as using the same spiral screw sense on each hemisphere. It is felt that this antenna has some definite advantages for broad-band operation with a relatively uniform field distribution.

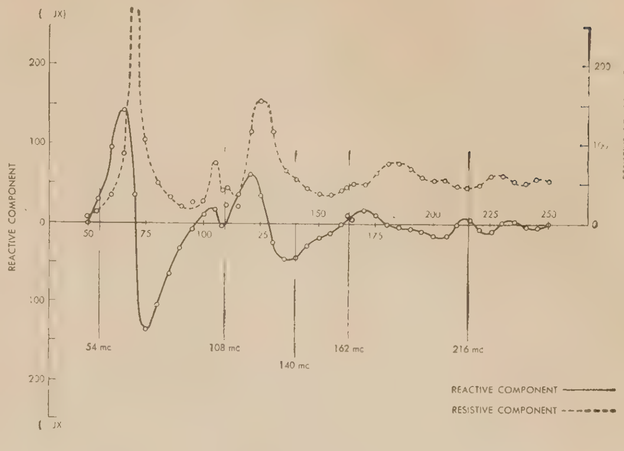


Fig. 12—Impedance data on APL/JHU sphere. Hemisphere with pole at $\theta = 0°$ only.

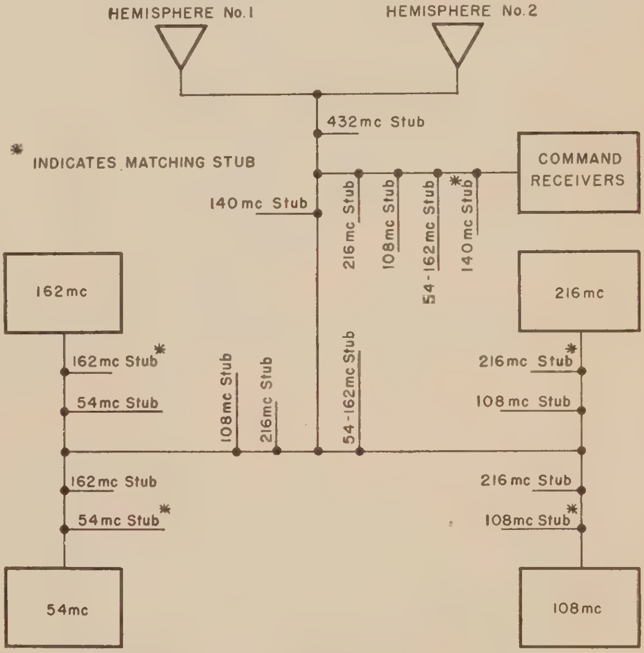


Fig. 13—Antenna matching and isolation network.

Acknowledgment

I wish to thank my associate in this work, R. M. Knight, Applied Physics Laboratory, The Johns Hopkins University, for his work and encouragement in performing many of the experimental tests, for performance evaluation. Also, the work of H. W. Haas and his associates at the Physical Science Laboratory, New Mexico State University, University Park, N. M., has been extremely helpful and is appreciated with many thanks.

Solar Batteries*

ARTHUR F. DANIEL†

Summary—The introductory part of this paper will provide a brief summary of how recent advances in military electronics for ground and space applications have created an urgent need for new energy sources and power supplies. In this search for new sources of power, considerable attention is being devoted to the utilization of solar energy.

A short summary will be provided of the applications of USASRDL-developed solar cells in the satellite field to date. This will include a discussion of the apparent reliability and efficiency of solar cells in operating situations and the environmental factors affecting solar cells. A brief discussion will be given of the various methods of mounting solar cells with succinct comments on the advantages and disadvantages of different methods. Reference will also be made to USASRDL quality control methods and the quality vs cost problem.

The primary portion of the paper will be devoted to a detailed discussion of those energy conversion devices which employ static methods for direct conversion of solar energy to electrical energy, *i.e.*, those types which utilize the thermoelectric, Edison (thermionic emission), photovoltaic and photoemission effects.

The relative merits of these systems based on present and anticipated conversion efficiencies are reviewed, in brief, for guidance as to future possibilities of these types of devices and their utilization in the satellite program.

RECENT advances in military electronics for ground and space applications have created an urgent need for new energy sources and power supplies. In this search for new sources of power, considerable attention is being devoted to the utilization of solar energy.

Under the title "Solar Batteries," those energy conversion devices which employ static methods for direct conversion of solar energy to electrical energy will be discussed, *i.e.*, those types which utilize the photovoltaic, photoemission, the thermoelectric, and the Edison (thermionic emission) effects.

The relative merits of these systems based on present and anticipated conversion efficiencies will be reviewed with emphasis on space applications. The theory of these systems has already been well covered in a number of presentations by various authors and this information is readily available in the literature [1]–[13].

PHOTOVOLTAIC EFFECT

The photovoltaic effect has been successfully employed for the conversion of solar energy to electrical energy in Vanguard I, Sputnik III, and Explorers VI and VII, through the use of the silicon photovoltaic cell, quite often called a solar cell or solar battery, originally developed by the Bell Telephone Laboratories [14], [15]. A number of space vehicles to be launched in the near future will also depend on this type of solar power supply.

Silicon solar cells having efficiencies in the order of 9 to 10 per cent are now obtainable in reasonable quantities. In outer space, for earth orbiting satellites, solar energy is available at the rate of 2 cal/cm^2/minute or 1400 watts/meter^2 or 440 BTU/square foot^2/hour, with the receiver at normal incidence. Assuming an efficiency of 10 per cent (sea level reference 1.5 cal/cm^2/minute cell temperature at 25 degrees C) 14 mw/cm^2 of active cell surface is realized. In an actual design of a solar power supply, consideration is given to the type of orbit, duty cycle, spinning or oriented vehicle, cell temperature, erosion of protective covers by micrometeorites (dust), spectral shift from sea level to outer space, and protection for the cells during preflight tests and handling in addition to conditions existing during the launching period. After corrections for the above conditions, 8 mw/cm^2 or 7.4 watts/square foot of active cell area is generally considered available. A power-to-weight ratio of 0.25 watt/pound, including storage system, for a nonoriented satellite was achieved in an actual solar power supply, shown in Fig. 1 mounted on the satellite. The power supply [16], including the sealed nickel cadmium storage batteries, weighed $22\frac{1}{2}$ pounds. The nonoriented solar power supply was rated at 5 watts and weighed $17\frac{1}{2}$ pounds. If orientation were possible, using similar design methods, a power to weight ratio of 1.5 watts/pound would have been possible instead of the 0.25 watt/pound which was realized.

Looking into the near future, it is expected that 1×2-cm cells with efficiencies in the range of 12 to 15 per cent can be obtained in reasonable quantities. Because of the expected future higher power requirements, oriented expansible arrays of cells must be employed. The use of oriented arrays affords new possibilities in limiting the equilibrium temperature of the cells to the order of 0°C or lower. This low cell temperature can be achieved through the use of spectrally selective optical coatings which would increase the emissivity of the cell surface in the far infrared and reject radiant energy in the portions of the spectrum not utilized by the cell; it can be achieved by providing a good thermal path from the back of the cell to the rear surface of the array and by coating the rear of the array to obtain high surface emissivity to take advantage of the cooling effect of space. Even lower cell temperatures are a definite possibility. Initial information from the "paddlewheel" (Explorer VI) satellite indicates that the temperature of the cells is about 8°C.

The efficiency of a photovoltaic cell increases with a decrease in temperature. For instance, a cell with an efficiency of 12 per cent at 25°C will have an efficiency of 13 per cent at 0°C. Assuming that cells with an efficiency

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* Original manuscript received by the IRE, December 2, 1959.

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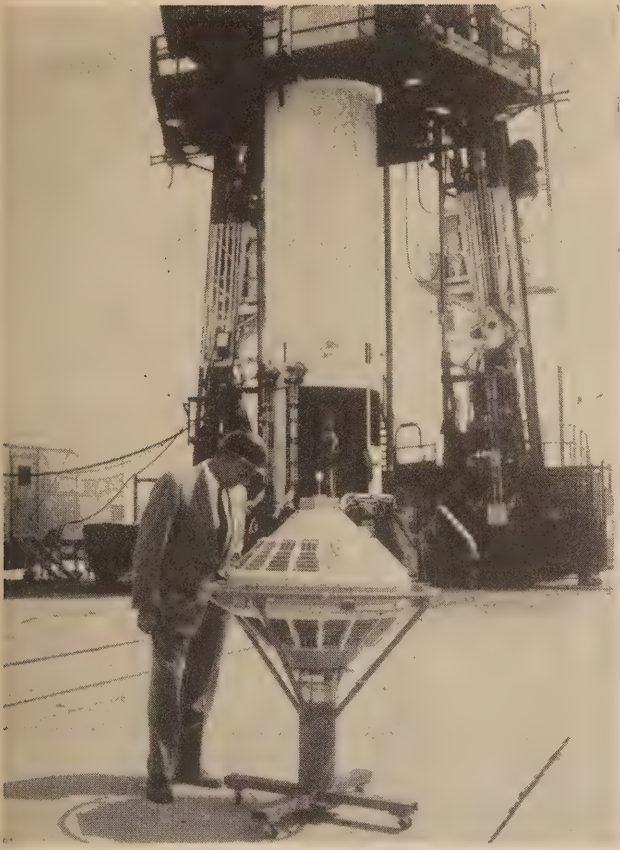

Fig. 1—Explorer VII showing solar power supply. Dr Kurt Debus, director of the Army Ballistic Missile Agency's Missile Firing Laboratory, looks over the Explorer VII satellite at the launching site. The 91.5-pound satellite was placed in orbit by the Juno II rocket shown in the background (U. S. Army photograph).

of 12 per cent (25°C) are available and that a cell temperature of 0°C can be obtained, an output of 18 mw/cm^2 of active cell surface can be realized. Compensating for transmission losses through cell covers sand blasted by meteoritic dust and the so-called spectral shift, the output is reduced to 14 mw/cm^2 or 13 watts/square foot. Using this figure with present design methods for the mounting of cells, orientation of plaque, and required protective covers and housing, a figure of 3.5 watts/pound (including storage batteries) can be calculated for the power output.

Programs are now in effect for the investigation of new materials for solar cells, multilayer and variable energy gap cells for greater utilization of the spectrum, high efficiency silicon cells, large area cells, multiple junctions on a single thin film of silicon, and high temperature cells. As a result of these efforts, efficiencies of 15 per cent for single gap cells and efficiencies of 20 to 30 per cent for cells of new materials and devices utilizing a greater portion of the spectrum may be possible. Present costs for photovoltaic cells are high and a program has been initiated for the investigation of methods leading to high production yields of efficient cells at a reasonable cost.

PHOTOEMISSION EFFECT

The photoemission effect [3], [4], [5], [6], [12] has been known for many years but little effort has been made in the past to use it for the conversion of radiant energy into electrical energy of sufficient magnitude for use as a source of power. A photoemission diode is analogous to the thermionic diode. When the photoemissive layer is illuminated, light photons release their energy to the electrons upon collision. If the amount of energy is greater than the work function of the material, the electron escapes with a kinetic energy equal to the excess of the quantum energy over the work function and it will reach the anode. In the thermionic diode, the anode is maintained at a lower temperature than the cathode, but in the photoemission diode, the anode is kept "dark," to prevent emission which would result in an opposing current. It is also subject to space charge limitations. Recently, several organizations have been investigating the possibility of increasing the efficiency of a device utilizing this effect, and 3 per cent appears obtainable. The chief advantages for this device are a high power-to-weight ratio and relatively low cost-per-unit power. Preliminary calculations indicate that approximately 3 kw of power at 28 volts can be obtained if the cells are mounted on a 30-foot diameter balloon. Fifty to 150 watts/pound appears feasible. The material costs are fairly low and large area devices may possibly be fabricated by vapor deposition of the photoemissive materials.

THERMOELECTRIC EFFECT

Solar powered thermoelectric generators are being considered as a source of power for space applications. Many groups are actively engaged in the investigation of thermoelectric materials and generator design. A survey of the literature and reports resulting from various programs sponsored by the Department of Defense indicates that a number of thermoelectric materials have been investigated and their efficiencies over a given operating temperature range have been determined. Fig. 2 and Fig. 3 show the efficiencies of N- and P-type materials in terms of a figure of merit, Q^2/pK, when $Q^2 = \text{volts} \times \text{deg}^{-1}$, $p = \text{ohm}^{-1} \times \text{cm}^{-1}$, $K = W \times \text{deg}^{-1} \times \text{cm}^{-1}$, which is based on the measured thermoelectric properties of the materials. It does not represent the over-all efficiency obtainable in a generator where losses caused by contact resistance between members of the thermocouples, lateral heat losses, and transfer of energy from the source to the hot junctions must be taken into consideration. For example, the over-all efficiency of a solar powered thermoelectric generator will be

$$\text{Efficiency} = \frac{\text{Electrical output}}{\text{Total intercepted energy}}.$$

It can be seen in Figs. 2 and 3 that the materials with the highest figures of merit are P-type $BiSbTe_3$(Se) and

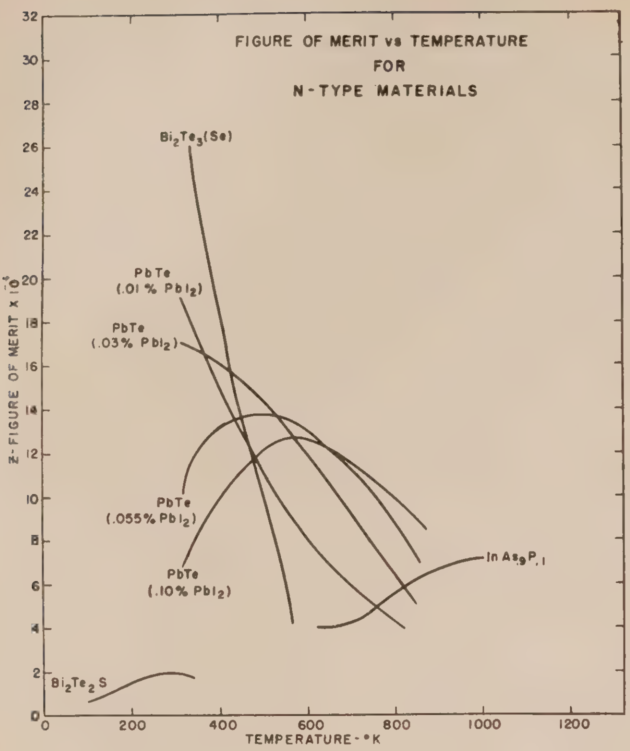

Fig. 2.

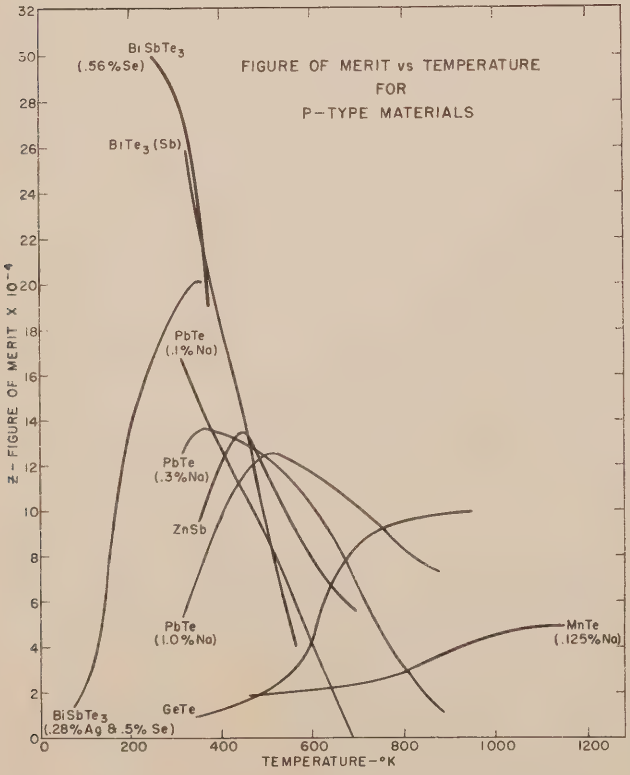

Fig. 3.

N-type $Bi_2Te_3(Se)$. Because of the low melting points of these materials, however, their use in a solar-powered thermoelectric generator does not appear feasible. Materials capable of operating at higher hot junction temperatures are required in order to obtain a reasonable Carnot efficiency. A recent paper [17], discusses the merits and design problems of a solar-powered thermoelectric generator and its possibilities for space use. Since the data presented was obtained from the performance of an actual device, it will be used later in this discussion for comparison to other systems.

Thermionic Emission

Considerable effort is being devoted to the utilization of the Edison effect as a means of converting thermal energy into electrical energy. A number of laboratories are actively engaged in this field and claims of efficiencies of 10 per cent for the close spaced vacuum diode have been made and predictions of efficiencies up to 40 per cent for the Cesium vapor type have appeared. As for its present and future possibilities in space applications, a recent paper [3] gave a comprehensive engineering analysis of a thermionic power supply using solar energy as a heat source. The data presented will be used as a basis for comparison with other systems later in this discussion.

Comparison of Conversion Systems

In comparing the relative merits of these various systems for the direct conversion of radiant energy from the sun to electrical energy, a number of factors must be taken into consideration. Some of these are listed below:

Reliability,
Power per unit weight, area or volume,
Complexity of the system,
Damage by meteorites; punctures and erosion,
Radiation damage,
Operating lifetime,
Mechanical problems introduced by use of expansible arrays, concentrators, pumps,
Accuracy of orientation,
Effects of drag and radiation pressure on large collector surfaces,
Effects of zero gravity,
Conversion of electrical output to usable form.

The basic difference between these four systems is that the photoelectric and photoemission devices convert the direct incident radiation. The thermoelectric and thermionic devices are essentially heat engines and require the concentration of the incident radiation to the device or heat sink to achieve the required rate of heat flux per unit of cathode or heat sink area. The use of solar concentrators introduces a number of problems that require serious consideration. For temperatures in the order of 500 to 750°C, required for thermoelectric generators, small errors in collector geometry and orientation can be tolerated. For temperatures in the order of 1000°C and above for thermionic diodes, a high degree of accuracy in collector geometry and orientation is essential for reasonable collection efficiencies. Thermal energy conversion systems must include a means for transferring the heat from the receiver or sink to the conversion device possibly by means of a circulating heat transfer fluid and transferring the waste heat to a radiator for rejection to space. Circulating pumps will be required to accomplish this in a zero gravity environment.

Consideration has been given to various types of energy storage systems capable of furnishing power during the dark periods of the orbit. The storage of thermal energy has been suggested as an alternate means for the electrochemical storage battery. If the power requirements for a particular vehicle are such that the load is a continuous one, a thermal energy storage system may be satisfactory. If peak power demands are involved, a thermal energy storage system will not be adequate because of the thermal lag in such a system and, in addition, the conversion device will have to be designed for this maximum power. This will introduce a voltage regulation problem, particularly for the thermoelectric generator. The output voltage would change considerably from peak load to average load. It appears more practical to use an electrochemical storage system which will be capable of supplying the peak loads with adequate voltage regulation and design the conversion device to supply the average power on the light side of the orbit with additional capacity for the recharging of the storage batteries.

Another problem involving the orientation of solar concentrators or solar cell arrays is the degree of accuracy required. For a solar cell array, a deviation of 20° from normal incidence only results in a loss in power of approximately 6 per cent. For solar collectors with fairly high concentration ratios, accuracy of orientation of 1° or less is necessary. This imposes a severe requirement on the orientation system and indicates a need for accurate resetting on the dark side of the orbit in order to minimize the time required for orienting the solar collector upon entering the light side of the orbit. If this time is appreciable, it may represent a significant portion of the light side period of the orbit.

The effects of erosion or punctures by micrometeorites present problems for all four systems. The erosion of the active surfaces of photovoltaic cells can be prevented by providing them with protective, transparent, and radiation resistant covers. Allowances must be made for the transmission losses in this cover, including the losses that will eventually occur when it becomes frosted because of sandblasting. The effects of punctures resulting in a loss of a cell or cells by larger particles can be compensated for. The cells are usually arranged in series-parallel groups and allowances can be made in the design for loss of a certain number of modules. The possibility of erosion by dust and sputtering caused by the impact of high energy atoms or molecules of the highly reflective surfaces of a solar concentrator must be taken into consideration. The possibility of providing a protective cover for solar concentrators does not appear feasible. Punctures would remove only a very small fraction of the total collector surface area. In applications where heat transfer loops are used from the source to the conversion device and from the device to a heat exchanger for rejection of waste heat, punctures of these components by meteorites would tend to be catastrophic, particularly in those using a liquid heat transfer medium.

Radiation damage to the various components employed in these systems does not appear to be a serious factor. The solar cells on Vanguard I have been operating continuously since March 17, 1958. The Russians [2] claim that the solar cells on Sputnik III have not been affected by radiation. The use of organic materials in construction of these systems introduces a radiation damage problem. This problem is difficult to solve because there is insufficient knowledge of the deleterious effects that may occur in a large portion of the ultraviolet spectrum. A high vacuum environment may also cause a degradation of organic materials. The use of spectrally selective coatings for the heat sink to make it an efficient absorber or as a means to obtain a low ratio of absorbtivity vs emissivity for solar cells and the structural materials of the array is being investigated. The stability of these coatings under radiation and a high vacuum environment and under conditions of high humidity prior to launching will have to be determined.

The four solar energy conversion systems being considered here do not carry their prime energy source with them as is done in chemical or nuclear energy conversion systems. Rather, the solar energy is converted to electrical energy at the point at which it is available. The essential factors to consider then would be the power per unit of weight and per unit of area, system complexity and reliability, operating lifetime of the conversion device, effects of space environment and cost. The one system that has been proven in actual use in space applications is that employing the photovoltaic cell and electrochemical storage batteries [16]. Information for use in comparing the merits of the other systems to that of the photovoltaic cell is in the form of engineering estimates based on present results obtained on experimental models and predicted future capabilities of the conversion device. With this in mind, some approximate figures, as shown in Table I, can be arrived at to indicate the possibilities of these four systems.

At the present time, the photovoltaic system appears to offer the highest watts/square foot and highest system efficiency and the lowest watts/pound. The thermionic and thermoelectric systems require solar concentrators and the efficiency of these devices depends on the

TABLE I

System	Watts/Pound		Watts/Square Foot of Collector Intercept Area		Possible System[4] Efficiencies	Life of Conversion Device
	Present	Future	Present	Future		
Photovoltaic	1.5	5	7.4	13.5	10–12 per cent	2 years or more
Thermionic [1]	7.2[1]	17	2.2	3.5	2– 4 per cent	Not determined
Thermoelectric [17]	20[1,2,3]	30[2,3]	0.3	1	2– 3 per cent	Not determined
Photoemission	—	50–150[3]	—	3	2– 3 per cent	Not determined

[1] Experimental.

[2] The watts/pound are only for the thermoelectric materials.

[3] Does not include storage system.

[4] System efficiency is defined as $\text{Efficiency} = \dfrac{\text{Electrical output}}{\text{Total intercepted energy}}$.

accuracy of the reflector surfaces and orientation. Efficiencies of 60 per cent have been indicated for concentrators assuming geometrical perfection and proper alignment. Efficiencies in the order of 30 to 40 per cent appear more likely for large expansible concentrators. This low concentrator efficiency imposes a penalty on the thermionic and thermoelectric systems. This is indicated in Table I where the power output in terms of watts/square foot of collector intercept area is shown for the four systems. This is further illustrated by comparing the required collector intercept area for a thermionic system [1] where 4680 square feet are required for a 10-kw power supply employing diodes with a 5 per cent efficiency. If photovoltaic cells covered an equivalent area and produced 7.4 watts/square foot, the power output would be in the order of 34 kw. To produce 10 kw, only 1350 square feet would be required. To be competitive with the other systems, more efficient, high temperature materials will be required for the thermoelectric system. The photoemission system is in its early stages of development. Present indications are that it could offer the highest watts/pound and possibly eliminate the need for orientation if mounted on a balloon, but would require large surface areas.

CONCLUSION AND RECOMMENDATIONS

It is not possible, at this time, to reach any decision as to which of the direct energy conversion systems will eventually be superior. A number of factors have to be considered. System efficiency is only important where it eventually determines total system weight. If weight is no longer of major importance and the problems of storing and protecting large collectors during launch, their erection and orientation in space, and the effects of radiation pressure and drag in low altitude orbits, are major ones, then system efficiency becomes an important factor. Reliability and lifetime of the conversion device are of major importance. The photovoltaic and photoemission systems appear to have advantage over the other more complex systems. The effects of radiation and damage by micrometeorites are common problems for all systems. A zero gravity and high vacuum environment will be a greater problem for systems employing heat transfer loops and radiators for rejection of waste heat. It does not seem reasonable to assume that any one system will be used for all space applications.

Although all of the solar energy conversion systems are in relatively early stages of their development, the photovoltaic system has frequently been referred to as the "Work Horse" of these systems, and it may have to carry the major load of direct solar energy conversion for a number of years. Because of the state of development, an accurate and realistic estimate of the future practical possibilities of these systems is impossible at this time. Research and development in these areas should be vigorously pursued in order that the most effective system can be determined and the best solar energy conversion devices can be developed for space applications.

ACKNOWLEDGMENT

I wish gratefully to acknowledge the very valuable assistance of G. Hunrath of the Power Sources Division, U. S. Army Signal Research and Development Laboratory, whose help in collecting and assembling material for this article was invaluable.

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Radiative Cooling of Satellite-Borne Electronic Components*

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Summary—**The basic principles of radiative cooling of electronic components and subassemblies in a satellite are discussed, and estimates are made of the lowest temperatures attainable in a satellite by completely passive means. It appears feasible to maintain some compartments within a satellite at temperatures of 250°K or lower, so an opportunity is presented for refrigerating components whose characteristics are enhanced at lower temperatures.**

INTRODUCTION

NOISE in many electronic components is reduced at lower temperatures. In view of the current attention being directed toward electronic equipment for satellite installation, it is of interest to estimate the lowest temperatures which can be obtained by completely passive means in a satellite.

SATELLITE HEAT BALANCE

In a satellite at stable-orbit altitudes the only sources of heat are internally-dissipated power, solar radiation, earth radiation and perhaps lunar radiation. (Stellar radiation is insignificant.) A previous study[1] has shown that if a satellite has an outer skin coated with a material (such as white porcelain enamel) having a high reflectivity in the spectral region of most intense solar radiation and high emissivity at longer infrared wavelengths, its skin temperature will become no higher than 55°C at the central "hot spot" on the side toward the sun. A spherical satellite with such a skin coating, which distributes absorbed heat uniformly around the skin by conduction or by rotation to give uniform exposure to solar radiation, will be at a temperature of about −40°C. Hass, Drummeter, and Schach[2] have found that the skin temperature might drop as much as 40°C while passing through the earth's shadow. Therefore, −60°C (213°K) might be taken as the average skin temperature, and the lowest temperature at which a non-heat-dissipating electronic component insulated from the skin can be maintained. However, these estimates of the temperature neglect the effect of internally-dissipated power. If the combined effect of all additional heat sources is equal to that of solar radiation, the minimum temperature at which a non-heat-dissipating component can be maintained is of the order of $2^{1/4}(213°\mathrm{K}) = 253°\mathrm{K}$ or −20°C. The actual average temperature probably is lower than this, but higher than −60°C.

The above temperatures apply to small satellites which receive fairly uniform exposure to solar and earth radiation. The attainment of temperatures below those estimated here will require a larger satellite whose orbit and attitude minimize the exposure of a certain part of the skin to both solar and earth radiation.

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* Original manuscript received by the IRE, December 2, 1959.

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Assuming that an isolated section of the skin is not exposed to solar or earth radiation, let us evaluate the effect of lunar radiation. It is evident that at a location near the earth the maximum intensity of solar radiation reflected by the moon, plus solar radiation absorbed by the moon and re-emitted, can be no greater than $SA/2\pi R^2$, where S is the solar constant, A is the area of the lunar disk, and R is the distance from the earth to the moon. Inserting the values of A and R, it is found that the maximum intensity of lunar radiation is 1.11 (10^{-5}) of the solar constant. A gray body exposed to radiation of this intensity and no other heat source will stabilize at 22.6°K. If this radiation falls on a surface at 50°K, it will raise the surface temperature to $(22.6^4+50^4)^{1/4}$°K, which is less than 1°K above the initial temperature of 50°K. Therefore, we can conclude that the moon need not be considered as a heat source if the refrigerated components are to be at a temperature no lower than 50°K.

SOME RADIATIVE COOLING SYSTEM DESIGN CONSIDERATIONS

If the orbit and attitude of the satellite are such that neither solar nor earth radiation falls on the radiative heat sink, the low temperature limit will be imposed by thermal conduction from warmer parts of the satellite. Consider the cooling system schematic shown in Fig. 1. It will be assumed that the thermal gradients in the heat-conduction path are small so that the cooled component or subassembly, conducting bar, and radiator are all at the same temperature T_c. Then the equation governing the temperature is

$$k \frac{A_s}{b} (T_o - T_c) = A_r \epsilon \sigma T_c^4$$

where k is the thermal conductivity of the insulating material of thickness b, A_s is the total area of the insulated surface separating the cooling system from the rest of the satellite's volume, T_o is the temperature at the outside of the insulating layer, A_r is the area of the external radiator, ϵ is the emissivity of the radiator, and σ is the Stefan-Boltzmann constant.

If the insulating layer is of styrofoam, $k=0.25$ BTU hour^{-1} in feet^{-2} °F^{-1}. Reasonable values of A_s and b are 3 feet^2 and 2 inches. By internal radiation exchange, T_o will be approximately the same as the average skin temperature, 253°K. It will be assumed that $T_c=153$°K and $\epsilon=0.9$. Since $\sigma=1.825$ (10^{-8}) BTU foot^{-2} °K^{-4} hour^{-1}, it is found that A_r must be 7.5 feet^2.

With the values of the parameters chosen in the above example, radiative cooling may be difficult. Without investigating how low the thermal resistance of the cooling system must be to distribute the heat uniformly over so large a radiator, it is evident that such a value of A_r implies a larger value of A_s than was used in the example, unless the radiator is mounted outside the satellite. To keep such a radiator out of the sunlight, severe restrictions must be imposed on the satellite's attitude and orbit or a cumbersome assembly of external shielding baffles must be mounted around it.

The required value of A_r can be decreased by thicker insulation. Thus, if b is increased by a factor of 2 or 3 in the example, A_r becomes approximately the same as A_s, reducing the radiator to manageable proportions. In practice it may be necessary to pot the entire system in foam as shown in Fig. 2, with the outer skin in separate sections to reduce conduction of heat around the skin from warmer areas.

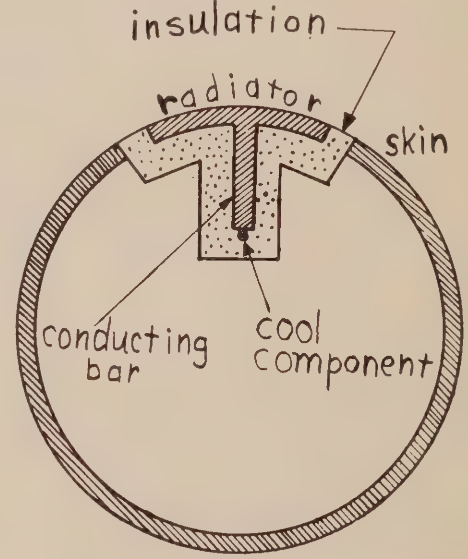

Fig. 1—Radiative cooling system schematic.

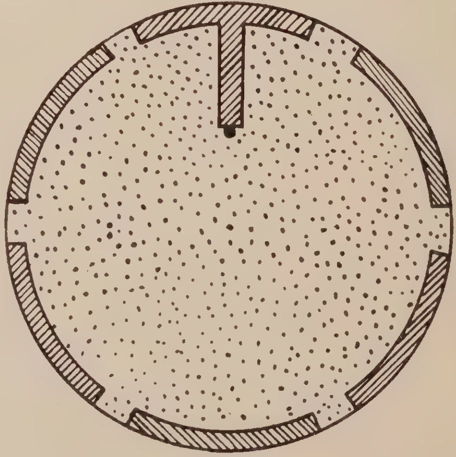

Fig. 2—Radiative cooling system potted in insulating foam in satellite with segmented skin.

CONCLUSION

With the proper skin coating, the attainment of temperatures below 250°K in a small satellite appears feasible if the ratio of internally-dissipated power to skin area is not excessive. In such a small "cool" satellite, components which require higher temperatures for proper operation must be in good thermal contact with heat-dissipating components, with relatively high thermal resistance between them and the skin.

If a larger satellite's orbit and attitude are such that an isolated section of its skin receives no radiation from the earth or sun, it might be possible to refrigerate a few components passively to temperatures as low as 150°K, keeping heat-dissipating components (and components which require higher temperatures) in contact with warmer skin sections. However, in addition to the obvious difficulties inherent in the attainment of such an orientation of the satellite, there will be problems in achieving structural strength while maintaining high thermal resistance between the refrigerated compartment and the remainder of the satellite's volume. Strengthening members will constitute thermal leaks through the insulation. Also, low thermal resistance in the conducting bar and radiator are to a certain degree incompatible with light weight.

Nevertheless, it may be feasible to maintain some electronic components and subassemblies in a satellite at temperatures below 250°K, so the possibility of taking advantage of these lower temperatures should be considered by designers of electronic equipment.

Extra-Terrestrial Radio Tracking and Communication*

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Summary—When the U. S. Army lunar program was initiated in 1958, the Jet Propulsion Laboratory (JPL) was assigned the responsibility for the upper rocket stages and the payload. Payload responsibility included radio tracking and communication with the lunar probe.

JPL's Microlock system, used for communicating with the early Explorer satellites, did not have sufficient range to perform this mission. Therefore, a new radio system designated TRAC(E) (TRacking And Communication, Extra-terrestrial) was designed. To the best knowledge of the authors, the TRAC(E) system is the first deep-space communication link to provide accurate tracking and telemetry data at lunar distances.

The design principles of the TRAC(E) system are presented in this paper in conjunction with a description of the equipment and actual performance data taken during the Pioneer IV lunar mission in March, 1959. The TRAC(E) system is an integral part of the NASA/JPL radio tracking station located near Goldstone Lake north of Barstow, Calif.

Future plans for improving the performance of the TRAC(E) system are indicated.

I. INTRODUCTION

THE TRAC(E) system is a versatile space communications system which is capable of simultaneous tracking and communication with earth satellites, lunar vehicles, or space probes. Two major questions which had to be answered in the design of such a communication system for extreme range applications were: What is the operating frequency? What is the size of the ground antenna? The ground antenna is considered in a separate report.[1] The factors which determined the operating frequency of the TRAC(E) system are outlined herein.

The transmitter in the space probe produces a signal power (P_t) limited by the efficiency of the transmitter and the weight of the vehicle electrical power supply. This power is beamed in the direction of the Earth-based receiver to provide an effective gain (G_t) of the signal power relative to radiation uniformly into space. The amount of beaming that can be realized is limited by the accuracy with which the vehicle's antenna can

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* Original manuscript received by the IRE, December 2, 1959. Portions of this paper were originated under studies conducted for the Dept. of Army Ordnance Corps under Contract No. DA-04-495-Ord-18. Such studies are now conducted for the Natl. Aeronautics and Space Administration under Contract No. NAS w-6.

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be pointed and/or its attitude controlled. Since the feasibility of vehicle-borne directional antennas for space communications has not yet been demonstrated, present vehicle antennas are gain-limited. Therefore, the signal power (P_r) received by an Earth-based station is given by

$$P_r = P_t G_t A_r \left(\frac{1}{4\pi R^2}\right). \tag{1}$$

The term R represents the distance between the space vehicle and the Earth-based station. The Earth-based antenna is assumed to be area-limited.[1] Examination of (1) reveals that the received power is independent of frequency, to a first order at least.

The choice of the operating frequency can be narrowed somewhat by choosing frequencies which are not seriously affected by the ionosphere (above 100 mc) nor by the atmosphere (below about 10,000 mc). With regard to interference, virtually every known source of radio interference decreases with increasing frequency. Of particular importance to space communications is the decrease in brightness temperature of the galaxy with frequency. The largest source of galactic interference lies along the Milky Way or galactic center in the band approximately 15 degrees wide lying near the possible destination and orbits of space vehicles. Reduction in this interference can be accomplished by using antennas with relatively narrow beamwidths and operating at the highest frequency that is practical.

In view of the factors considered above, the optimum communication frequency was actually determined by such factors as vehicle transmitter efficiency and ground receiver sensitivity, that is, state-of-the-art considerations. Within the time scale of the U. S. Army Lunar Program (which was subsequently transferred to NASA) and the weight limitations of the Pioneers III and IV Lunar probes, development of an efficient stable transmitter in the 1000-mc range appeared feasible. An operating frequency of 960.05 mc was eventually chosen.

The design of the TRAC(E) system is based upon phase-lock techniques which have been under continuing investigation and development at the Jet Propulsion Laboratory (JPL) since 1953.[2–5] The technique, used by JPL in the Microlock system,[6] permits use of receiver bandwidths significantly smaller than the Doppler shift expected from space vehicles and proper addition of a limiter provides near-optimum performance over a wide dynamic range of both signal and interference levels.[3] Action of the VCO is such that with proper design, the Doppler component is effectively removed at the first mixer which permits narrow-band predetection amplification. Telemetry subcarriers are synchronously detected, and the information is available at the output of the phase-locked FM discriminators.

II. TRAC(E) System for Pioneers III and IV

Fig. 1 is a functional block diagram showing the TRAC(E) system as it was originally designed for tracking and communicating with the Pioneers III and IV probes. In the probe transmitter, the 40.0021-mc crystal-controlled oscillator signal is phase modulated with telemetry subcarriers which contain the measured data as frequency modulation. The resultant phase-modulated signal is frequency multiplied by a factor of 24 and amplified to provide a 960.05-mc signal to the probe antenna. The transmitter signal output, normalized to unity, is

$$\text{Cos}\ [24\omega_c t + s(t)] \tag{2}$$

where $s(t)$ is the composite phase modulation signal.

The TRAC(E) receiver is a narrow-band phase-coherent double-conversion superheterodyne receiver which employs three balanced mixers at 960 mc, three balanced detectors at 30 mc, and four synchronous detectors at 455 kc. The mixers and detectors are three terminal devices having an input, a coherent reference and an output, and they perform the analytic function of multiplying the waveform of the input signal by the waveform of the reference. These devices in conjunction with three 30-mc IF preamplifiers, three 455-kc IF amplifiers, and the voltage-controlled local oscillator comprise the major portion of the ground receiving system. They are arranged in such a manner as to function as the differencing elements of four highly accurate servo systems: 1) the RF servoloop at 960 mc, 2) the AGC loop, 3) the declination servomechanism, and 4) the hour angle servomechanism.

The received signal is

$$A(t) \cos\ [24(\omega_c t - \phi_c) + s(t)], \tag{3}$$

where $A(t)$ is the signal amplitude factor of the space-to-earth signal at the ground station and

$$\phi_c = \frac{\omega_c}{c} \int_0^t \dot{R} dt,$$

radians, the Doppler shift on ω_c. The significant waveform equations for the TRAC(E) receiving system are listed in Table I. The numeral preceding each expression refers to the corresponding numerals in Fig. 1.

The system parameters which were used to achieve

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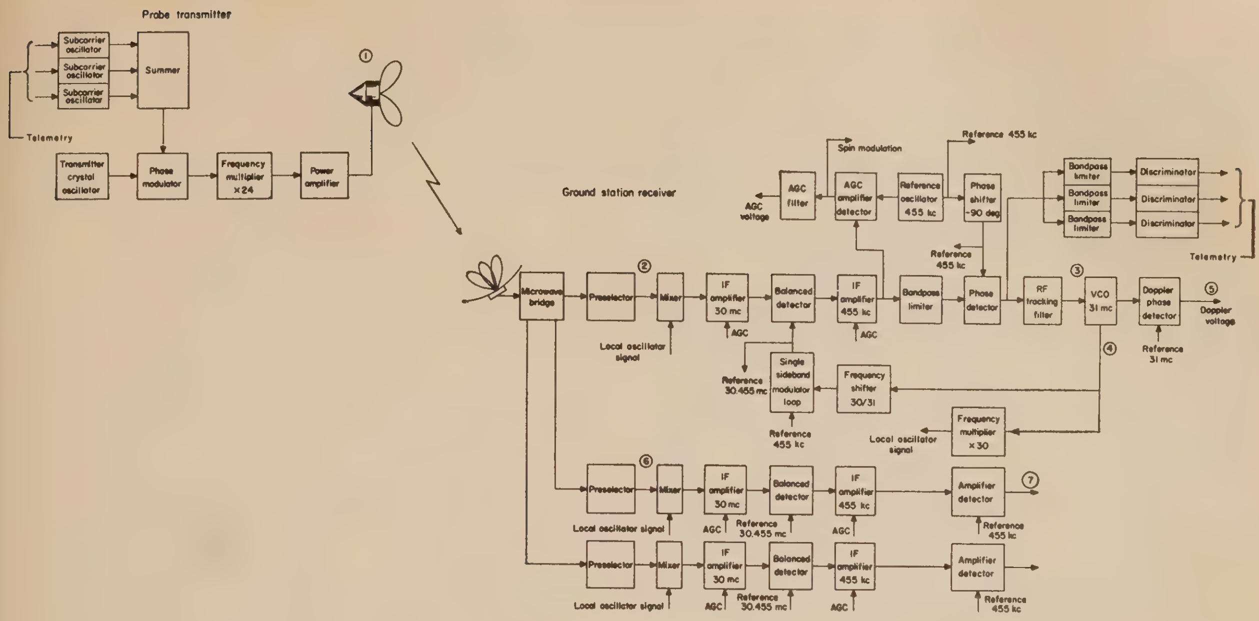
Probe transmitter
Subcarrier oscillator
Subcarrier oscillator
Subcarrier oscillator
Summer
Telemetry
Transmitter crystal oscillator
Phase modulator
Frequency multiplier ×24
Power amplifier
①
Ground station receiver
AGC voltage
AGC filter
Spin modulation
AGC amplifier detector
Reference oscillator 455 kc
Reference 455 kc
Phase shifter -90 deg
Bandpass limiter
Bandpass limiter
Bandpass limiter
Discriminator
Discriminator
Discriminator
Telemetry
Reference 455 kc
Microwave bridge
Preselector
②
Mixer
IF amplifier 30 mc
AGC
Balanced detector
IF amplifier 455 kc
AGC
Bandpass limiter
Phase detector
RF tracking filter
③
VCO 31 mc
Doppler phase detector
⑤
Doppler voltage
④
Reference 31 mc
Local oscillator signal
Reference 30.455 mc
Single sideband modulator loop
Frequency shifter 30/31
Reference 455 kc
Local oscillator signal
Frequency multiplier ×30
⑥
Preselector
Mixer
IF amplifier 30 mc
Balanced detector
IF amplifier 455 kc
Amplifier detector
⑦
Local oscillator signal
AGC
Reference 30.455 mc
AGC
Reference 455 kc
Preselector
Mixer
IF amplifier 30 mc
Balanced detector
IF amplifier 455 kc
Amplifier detector
Local oscillator signal
AGC
Reference 30.455 mc
AGC
Reference 455 kc

Fig. 1—Functional block diagram of the Pioneer IV transmitter and the Goldstone TRAC(E) System.

TABLE I

Waveform Equations Used in TRAC(E) System

(1) $A(t)\cos\left[24\omega_c t+s(t)\right]$

(2) $g_\Sigma(a)A(t)\cos\left[24(\omega_c t-\phi_c)+s(t)\right]$

(3) $\sin 24(\phi_c{}^*-\phi_c)\approx 24(\phi_c{}^*-\phi_c)$

(4) $\cos\dfrac{31\times 3}{30\times 4}(\omega_c t-\phi_c{}^*)$

(5) $\cos\dfrac{31\times 3}{30\times 4}\phi_c{}^*=\cos\left[\dfrac{31\times 3}{30\times 4}\right]\dfrac{\omega_c}{c}\displaystyle\int_0^t\dot{R}dt$

(6) $g_\Delta(a)A(t)\cos\left[24(\omega_c t-\phi_c)+s(t)\right]$

(7) $E\dfrac{A(t)}{A^*(t)}\dfrac{g_\Delta(\alpha)}{g_\Sigma(\alpha)}\approx\dfrac{A(t)}{A^*(t)}g_\Delta{}'(0)$

$A(t)$ = signal amplitude factor of the signal radiated from the probe
E = dc reference in the receiver AGC loop
c = velocity of propagation, meters/second
f_1 = measured frequency of the 31-mc Doppler reference
f_{c_0} = probe transmitter oscillator frequency with zero Doppler
f_d = measured frequency at the output of the Doppler phase detector
$g_\Sigma(\alpha)$ = voltage pattern of the main-beam antenna normalized so that $g_\Sigma(0)=1$
$g_\Delta(\alpha)$ = voltage pattern of the split-beam antenna normalized with respect to $g_\Sigma(0)$
$g_\Delta{}'(0)$ = slope of the $g_\Delta(\alpha)$ curve near $\alpha=0$, mils^{-1}
$s(t)$ = telemetry phase modulation
t = time, seconds
$\dot{R}$ = radial component of probe velocity meters/second $=c\left[1-\dfrac{960}{31f_c}(f_d+f_1)\right]$
α = tracking error of the antenna servo, mils
ϕ_c = Doppler phase shift on $\omega_c=\dfrac{\omega_c}{c}\displaystyle\int_0^t\dot{R}dt$, radians
ω_c = angular frequency of the probe transmitter oscillator $=2\pi(40.0021$ mc) radian/second
$\dfrac{1}{A^*(t)}$ = a measure of the voltage gain of the ground receiver so defined that the incoming signal $A(t)$ multiplied by the receiver gain figure $1/A^*(t)$ equals unity

accurate tracking and communication with the Pioneer IV probe to lunar distances and farther are listed in Table II. The 180 mw of transmitter power (±0.5-db power tolerance) was distributed between the carrier (96 mw) and the three telemetry carriers so that accurate tracking and reliable data transmission could be realized to at least 250,000 miles (lunar distance). Tolerances shown on the carrier (±0.3 db) and telemetry subcarriers (±0.5 db) apply to permissible variations in phase modulation index (±2° on each subcarrier). Examination of Table II shows that with the lunar probe at a range of 250,000 miles, the received carrier signal level is −141.1 dbm (decibels referred to one milliwatt). The resultant signal-to-noise ratios (S/N) in the RF loop, AGC loop, and angle tracking loop are 8, 39.7, and 38.2 db, respectively. This provided sufficient margin in signal level to insure successful tracking and communication. The significance of the bandwidths of the RF loop, AGC loop, and angle tracking loop shown in Table II is discussed later.

TABLE II

TRAC(E) SYSTEM CHARACTERISTICS FOR PIONEERS III AND IV

Transmitter Power, Total (at 250,000 miles)	180 mw ±20 mw (+22.5 dbm ±0.5 db)
Vehicle Antenna Gain	2.5 db ±1 db
Carrier Power	96 mw ±7 mw (+19.8 dbm ±0.3 db)
Subcarrier Power, Channel No. 1	14 mw ±1.5 mw (+11.5 dbm ±0.5 db)
Subcarrier Power, Channel No. 2	14 mw ±1.5 mw (+11.5 dbm ±0.5 db)
Subcarrier Power, Channel No. 3	36 mw ±4 mw (+15.5 dbm ±0.5 db)
Space Loss at 250,000 Miles	204.5 db
Ground Antenna Gain	41.8 db
Transmission Line Loss	0.7 db
Receiver Noise Figure	7.5 db
Receiver Bandwidth ($2B_{L_0}$) at Receiver Threshold	20 cps
Receiver Threshold	−154.1 dbm
Angle Track Loop BW ($2B_L$)	0.06 cps
Angle Track Loop Receiver Threshold	−179.3 dbm
AGC Loop BW ($2B_{L_0}$) at Receiver Threshold	0.025 cps
AGC Loop Threshold	−183.1 dbm
At 250,000 Miles	
Received RF Signal Level	−141.1 dbm
S/N for RF Loop	8.0 db
S/N for AGC Loop	39.7 db
S/N for Angle Tracking Loop	38.2 db

III. DESIGN OF TRACKING RECEIVER

The specifications for the TRAC(E) tracking receiver for Pioneers III and IV are shown in the Appendix. Reference is made to the literature[2,5,7–10] with regard to the development of these specifications. The 20-cps RF phase-locked loop noise bandwidth at threshold is determined by the stability of the transmitter and receiver oscillators. As a consequence, the sensitivity of the receiving system is limited by the threshold of the RF phase-locked loop. With an effective noise temperature (T_{eff}) of 1435°K resulting from a receiver noise figure of 7.5 db, an apparent antenna noise temperature of 42°K and an 0.7-db loss for the simultaneous lobing RF bridge and antenna transmission line to the receiver input, the threshold of the receiver is −154.1 dbm. This assumes that the antenna is looking at a low-noise region of the sky.

The AGC system has a closed-loop noise bandwidth of 0.025 cps at receiver threshold. With this noise bandwidth, spin rate and spin modulation depth for the lunar probe are measured as an error signal in the AGC loop. In addition, rms gain error is maintained to 0.1 db at receiver threshold.

Gain and phase tracking in the angle tracking receiver relative to the reference receiver is ±2 db and ±10°, respectively, for input signal levels from −45 dbm to threshold. Gain tracking maintains near-constant gain in the hour angle and declination servosystems. Phase tracking maintains shift in the electrical axis of the antenna system (due to phase shift) to ±0.01 angular mils (±0.0006°) for a 1° antenna error pattern s-curve with a 40-db null depth. The 0.06-cps closed-loop noise bandwidth for the angle tracking servo-system shown in Table II maintains rms angle jitter to 0.4 angular mils (0.022°) at receiver threshold.

IV. DESCRIPTION OF EQUIPMENT

Probe Transmitter

The transmitter for the Pioneer IV probe was located in the central 6-inch diameter well of the instrumented payload (see Fig. 2). Fig. 3 shows the flight transmitter mounted on the webbed platform that forms part of the payload structure and also supports the shutter experiment. Transistorized subassemblies are mounted on micarta disks, interposed between the webbing to provide thermal isolation. The vacuum-tube cavity is fastened directly to the center web so that the whole payload becomes a heat sink for the vacuum tube. The overall weight of the platform and transmitter is 1.33 pounds. The transmitter less platform weighs 0.98 pound.

Circuit design was concentrated principally in the areas that would insure early completion of a 960-mc transmitter having the objective specifications outlined in Table III. Some of the specialized components and their features that helped make an efficient 960-mc lunar-probe transmitter possible are: 1) the Western Electric GF 45021 transistor, with its ability to operate efficiently at VHF frequencies (100 to 300 mc) previously restricted to subminiature tubes; 2) the GE-7077, a subminiature ceramic UHF triode, which permitted the design of efficient, subminiature UHF cavity amplifiers; 3) the Bell Telephone Laboratories' "Varactor," a silicon junction reactance diode developed for the U. S. Army Research and Development Laboratories, that operates as a frequency multiplier with considerably higher conversion efficiency than conventional diodes;

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[7] W. K. Victor, "The Evaluation of Phase-Stable Oscillators for Coherent Communication Systems," Jet Propulsion Lab., California Institute of Technology, Pasadena, External Publication No. 337; May 8, 1956.

[8] A. J. Viterbi, "Design Techniques for Space Television," Jet Propulsion Lab., California Institute of Technology, Pasadena, External Publication No. 623; April 13, 1959.

[9] W. B. Davenport, Jr., "Signal-to-noise ratios in band-pass limiters," *J. Appl. Phys.*, vol. 24, pp. 720–727; June, 1953.

[10] W. K. Victor and M. H. Brockman, "The application of linear servo theory to the design of AGC loops," PROC. IRE, vol. 48, pp. 234–238; February, 1960.

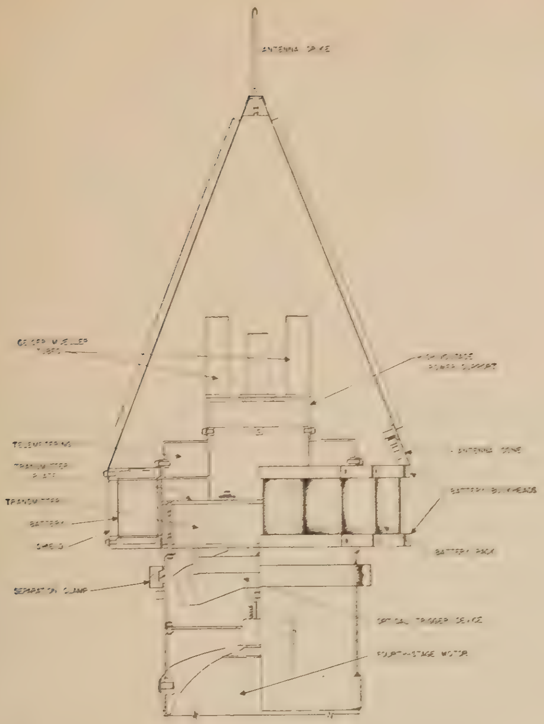

Fig. 2—Sketch of the Pioneer IV instrumented payload.

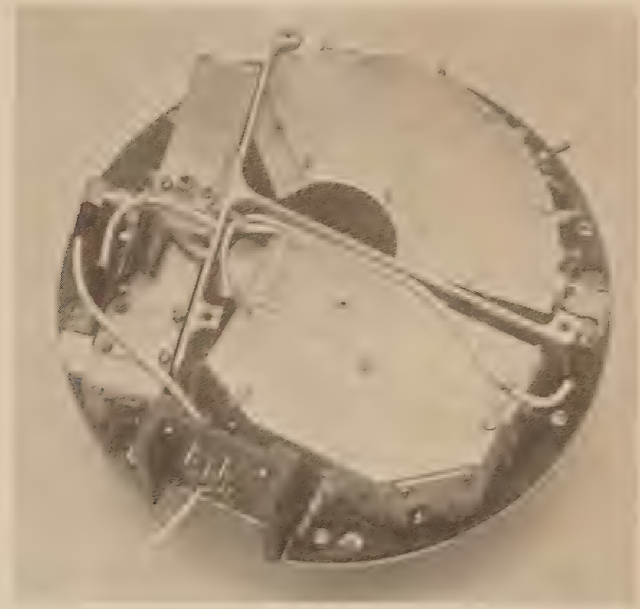

Fig. 3—Probe transmitter mounted on the webbed platform.

TABLE III
PROBE TRANSMITTER OBJECTIVE SPECIFICATIONS

Carrier frequency (nominal)	960 mc
Output power	180 mw
Crystal oscillator frequency (nominal)	40 mc
Short-term frequency stability—15 minutes	1 part 10^7
Long-term frequency stability	1 part 10^5
Power output stability	$\pm\frac{1}{2}$ db
Maximum incidental phase modulation	2 degrees per g
Over-all weight	0.9 pound
Over-all size 6-inches diameter × 1-inch height	28 inches^3
Primary power input	2.4 watts
Operating time with 6.5-pound battery	120 hours
Transmitter efficiency, exclusive of antenna gain	7.5 per cent

4) the ruggedized quartz crystal developed by the U. S. Army Signal Engineering Laboratories that enables phase-stable signals to be generated under conditions of extreme vibration; and 5) the development of reliable voltage-sensitive capacitors which simplify the design of the phase-modulation circuits.

Semiconductor devices operating in circuits from 40 to 960 mc provided the RF signal drive to the vacuum-tube power-amplifier which provided RF excitation to the probe antenna. The objective specifications of the probe transmitter (Table III) were achieved in the Pioneers III and IV experiments. The probe transmitter is described in detail in the literature.[11]

Ground Tracking Receiver (Goldstone Station)

The RF portion of the TRAC(E) receiving system is mounted in an electronics enclosure on the rear portion of the antenna reflector structure[1] (see Fig. 4). The UHF portions of the reference, hour angle and declination angle receiver channels which include three preselector cavities, three balanced mixers and three 30-mc IF amplifiers, is housed in a weatherproof enclosure (see Fig. 5). The UHF portion of the local oscillator system which includes a ×6 frequency multiplier, a three-way power divider, three UHF attenuators for local oscillator drive adjustment, and a crystal current meter circuit is mounted in a second weatherproof enclosure. Other weatherproof enclosures (see Fig. 5) contain power supplies and test equipment. The test equipment, which includes UHF and VHF signal generators and a noise-figure test setup, facilitates periodic checks of the receiver RF circuitry to insure optimum performance.

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[11] L. R. Malling, "A 960-MC Lunar Transmitter," Jet Propulsion Laboratory, California Institute of Technology, Pasadena, External Publication No. 596; January 7, 1959.

The amplified 30-mc output signals from the reference, hour angle and declination angle channels are transmitted from the electronics enclosure through coaxial cables to the receiver rack in the control building. The receiver rack comprises three cabinets containing the remainder of the receiving system, power supplies, and associated instrumentation (Fig. 6). The receiver system can be operated with a closed-loop RF bandwidth of either 20 or 60 cps which can be selected by means of a switch. Another switch permits selection of either an 11-second or a 300-second time constant filter for the AGC circuit. The system was operated in the 20-cps bandwidth and 300-second AGC filter time constant mode for the Pioneer IV experiment (Table II).

Operational control of the tracking system during a tracking operation is provided at the control console (Fig. 7). Control of both the tracking receiver and antenna servosystem is provided at the console. In general, the receiver and servosystems each have three basic modes of operation—manual, automatic track, and acquisition. In the acquisition mode, the tracking receiver and antenna search in frequency and angle, respectively, about the predicted frequency and angular position. Following acquisition, the received signal is automatically tracked in frequency and angular position.[12] Various receiver monitoring functions are provided at the control console.

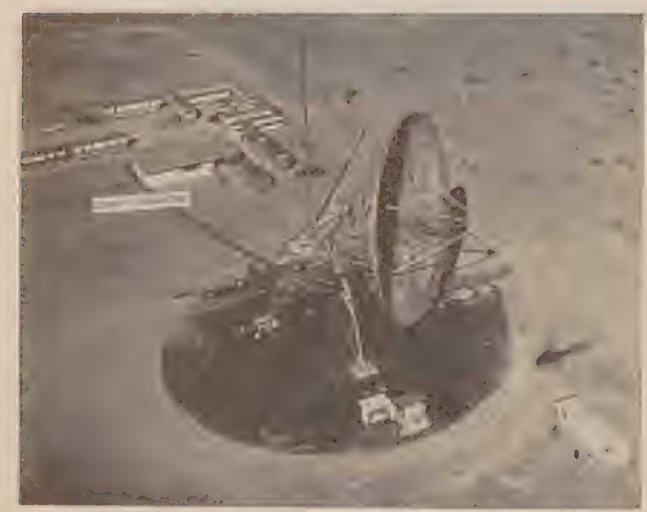

Fig. 4—Goldstone tracking station.

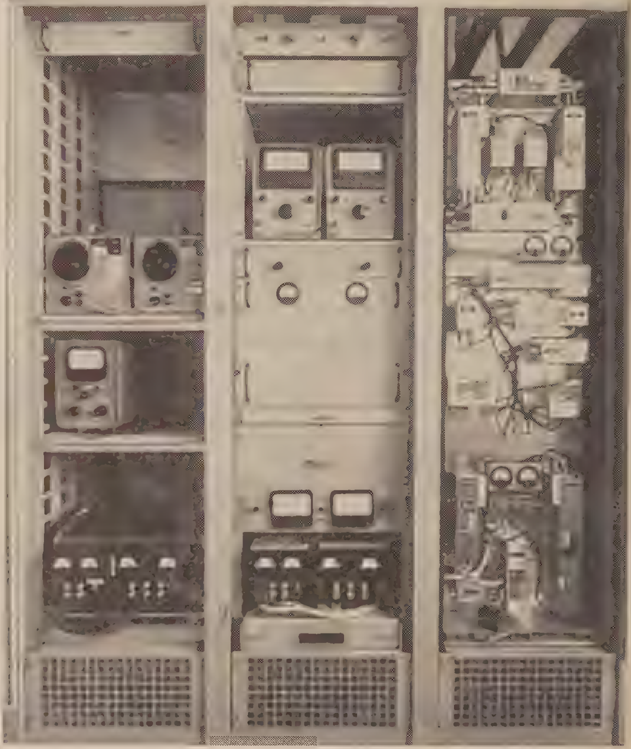

Fig. 6—Receiver rack.

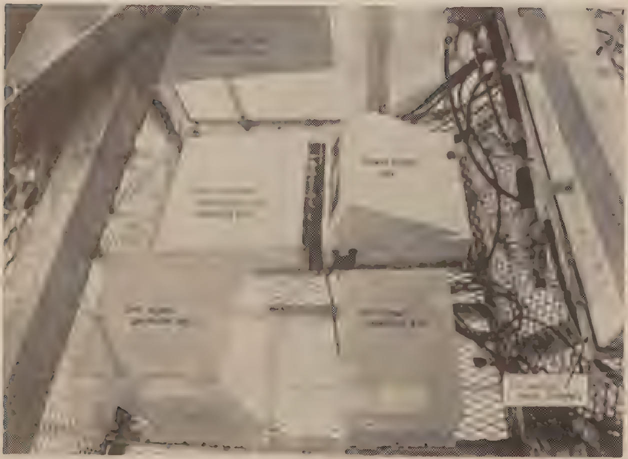

Fig. 5—Electronics enclosure.

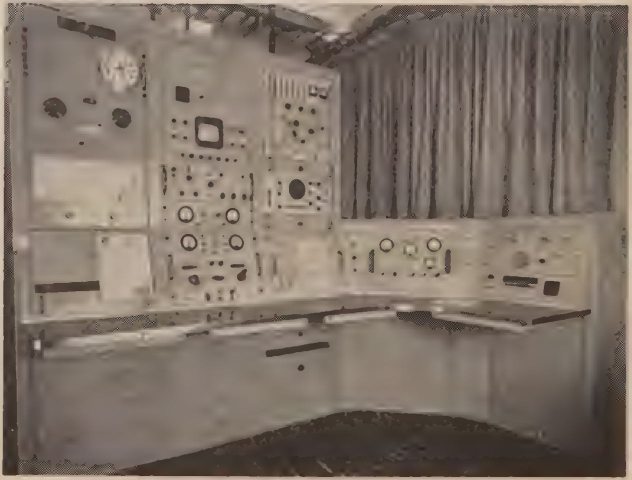

Fig. 7—Control console.

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[12] M. Eimer and R. Stevens, "Tracking and Data Handling for the Pioneer III and Pioneer IV Firings," Jet Propulsion Laboratory, California Institute of Technology, Pasadena, External Publication No. 701; August 14, 1959.

V. PERFORMANCE DATA FOR PIONEER IV LUNAR PROBE

Description of Pioneer IV Tracking

Following successful launching of Pioneer IV lunar probe at 05:10:56 GMT on March 3, 1959, radio tracking was accomplished through launch, injection, and coasting flight by the three JPL-operated stations (Cape Canaveral, Puerto Rico and Goldstone) out to a maximum range of 652,000 km (about 407,000 miles). At this range, after 82 hours and 4 minutes of flight, a rapid decrease in signal level occurred, as expected, due to loss of battery power. Prior to this event, received signal level was 5 db above threshold in a 20-cps bandwidth. After loss of signal during the fourth tracking period, a narrower bandwidth filter (10 cps) was installed in the tracking receiver, and the RF carrier was tracked for about 9 additional minutes. Had the batteries lasted, tracking could have been accomplished to a range of 1,850,000 km (1,150,000 miles) using the 10-cps filter.

Performance of the TRAC(E) tracking and communication equipment was highly satisfactory during this experiment. Performance data for the Goldstone Station are presented in the following material.

Received Signal Level and Spin Modulation: The noise figures of the Goldstone receiver based on data taken March 1 and 3, 1959, were as follows:

Reference Channel	7.5 db,
Hour Angle Channel	7.15 db,
Declination Channel	7.25 db.

The measured noise figure of the reference channel agreed with the nominal value of 7.5 db. The theoretical receiving system sensitivity based on unity signal-to-noise ratio in a 20-cps bandwidth, a receiver noise figure of 7.5 db (effective noise temperature 1355°K), an apparent antenna noise temperature of 42°K and a total loss of 0.7 db for the antenna simultaneous lobing bridge system and transmission line to the receiver input is −154.1 dbm. The measured receiver sensitivity curve is shown in Fig. 8.

A comparison of measured with calculated signal level is shown in Fig. 9(a) for each tracking period for the Pioneer IV experiment. Throughout the tracking operation, the measured values are 3 to 5 db less than the calculated curves (based on nominal values and assumed vehicle attitude).

After despin at 16:32:24 GMT on March 3, the amplitude modulation of the signal resulting from spin and precession occurred at frequencies of 0.23 cps and 0.046

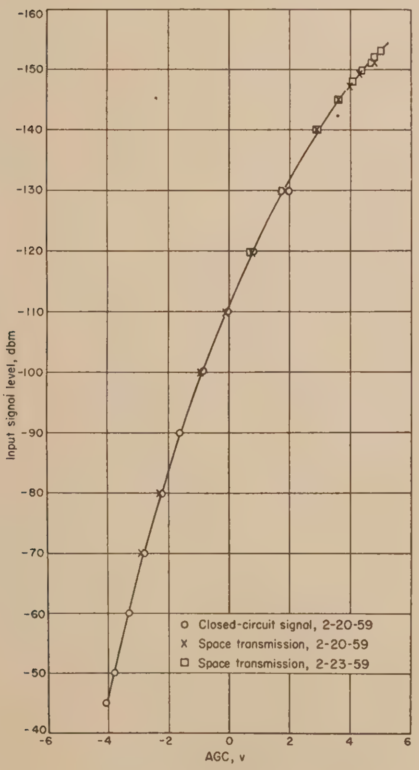
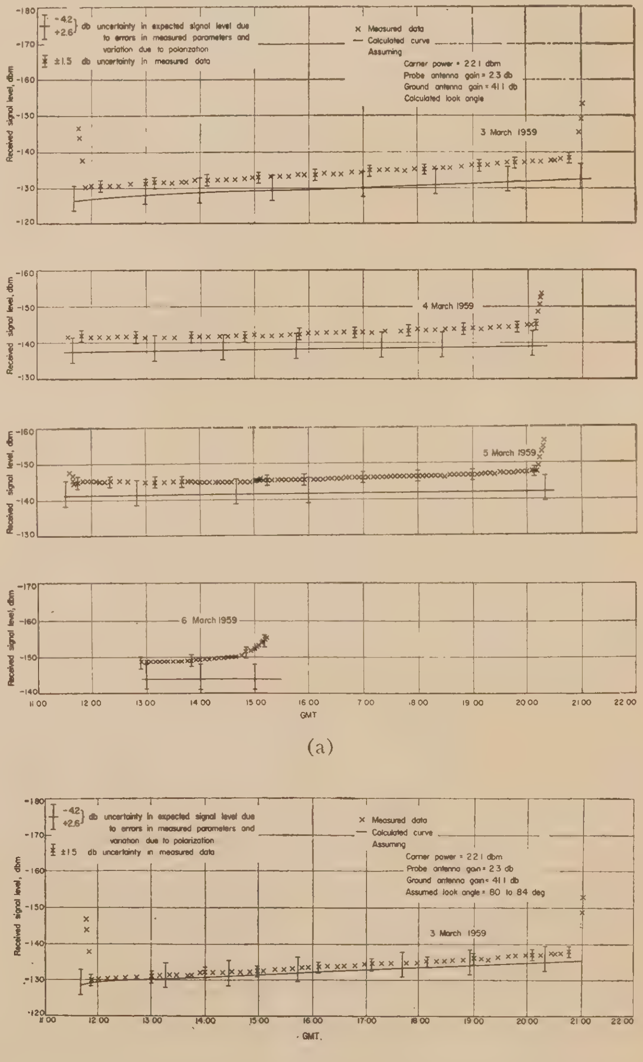


Fig. 8—Receiver sensitivity.



(a)

(b)

Fig. 9—Comparison of measured and calculated values of received signal level.

TABLE IV

RANGE AND SIGNAL LEVEL DATA FOR PIONEER IV

Tracking Period No.	Date	Time	Range Kilometers	Signal Level at Acquisition dbm	Signal Level at Loss of Lock dbm	Change of Signal Level (Neglecting Horizon Effect)	
						Measured db	Expected db
1	March 3, 1959	11:47:00 to 21:05:48	97,400 to 194,000	−144.5	−154.5	7.5	6.1
2	March 4, 1959	12:33:54 to 21:15:53	315,000 to 380,000	−141.5	−154.0	2.5	1.7
3	March 5, 1959	12:34:52 to 21:18:46	487,000 to 545,000	−147.5	−156.5	2.0	1.0
4	March 6, 1959	12:50:00 to 15:16:19	644,000 to 657,000	−150.5	−156.2	0.7	0.2

cps with a maximum modulation depth of 3 to 3.5 db and a minimum depth of 1 to 1.5 db. If the look angle between the spin axis and the line-of-sight to the probe is assumed to be 80° with a precession angle of 10°, the antenna pattern measurements agree with the observed depth of spin modulation, and the average signal strength comparison would appear as shown in Fig. 9(b) for the first tracking period.

The received signal levels were determined by measuring the AGC voltage with a digital voltmeter and converting this to signal level, using the receiver sensitivity curve (see Fig. 8). The measured values are indicated by the symbols in Fig. 9. In general, the slopes of the measured curves are slightly greater than the expected slopes. The signal levels at acquisition and loss of signal and the changes in level for each period are shown in Table IV. The estimated uncertainty of ±1.5 db in the measured data is based upon the following:

Receiver sensitivity error	±1 db,
Recording, calibration, and data reduction errors	±0.5 db.

In Fig. 9 the expected signal level is shown for comparison with the measured data. The solid line represents the signal level calculated on the basis of the following:

Transmitted carrier power	22.1 dbm
Vehicle antenna gain	function of look angle (see Fig. 10)
Ground antenna gain	41.1 db (indirect measurement)
Space attenuation (db)	92.1+20 $\log_{10}$ (range in kilometers).

The look angle is calculated on the assumption that the spin axis of the probe is essentially colinear with the velocity vector at injection (look angle varies from 45.5 to 56.2° for the experiment). The vehicle antenna pattern of Fig. 10 is based upon the measurements of antenna gain as a function of look angle and rotation of the antenna. The solid curve which was used for calculating signal level represents the geometric mean of the gain for full rotation at the given look angle. The dashed curves show the maximum and minimum gain and indicate the degree of amplitude modulation to be expected at each given look angle. The uncertainty of the calculated data is based upon the following:

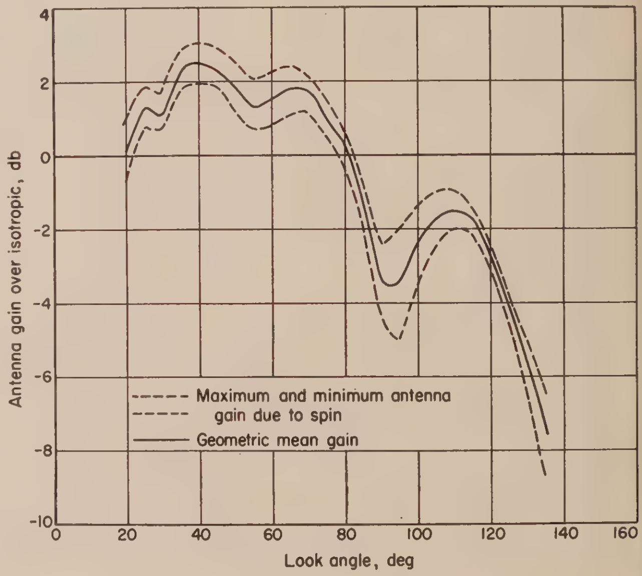


Fig. 10—Vehicle antenna pattern.

Ground antenna gain (variation due to polarization	$\left.\begin{matrix}-1.7\\+0.1\end{matrix}\right\}$ db
Ground antenna gain (uncertainty)	±1 db
Transmitter power	±0.5
Vehicle antenna gain	±1.0
This gives a total uncertainty in the calculated data of	$\left.\begin{matrix}-4.2\\+2.6\end{matrix}\right\}$ db.

The measured signal levels are less than the expected values by 3 to 5 db. While the regions of uncertainty of the calculated and observed data overlap slightly, it is believed that the difference between expected and measured values is of the order of 3 db. This apparent loss of signal can be explained by assuming a look angle of the order of 80°.

Angle Tracking System: The reduction of tracking data was essentially a problem of filtering, by statistical analysis, the random observational errors and the sys-

TABLE V

Long-Term System Capabilities

Characteristic	Capability		
	1958	1960	1962
Transmitter Power	0.2 watt	10 watts	100 watts
Vehicle Antenna Gain	0 db	16 db	36 db
Receiver Sensitivity:			
Noise temperature	2000° K	400° K	40° K
Bandwidth	30 cps	30 cps	30 cps
Earth-vehicle range for 10-db S/N ratio	4×10^5 miles	4×10^7 miles	4×10^9 miles

tematic bias errors. The computational program for generating the Pioneer IV trajectory is described in detail in a JPL external publication.[12] The trajectory angles were corrected for atmosphere refraction and all known mechanical sources of error then compared with unsmoothed raw data for the last day of tracking (March 6, 1959). The hour angle errors for this period ranged from 0.035 to −0.11°. Near threshold, the hour angle errors were +0.02 to −0.1°. Using smoothed values of observed data, the hour angle error was about −0.03° at the system threshold. The declination errors for the same period ranged from +0.07° to −0.04°. Using smoothed values of observed data, the declination error was about 0.02° at threshold. As indicated in an earlier portion of this paper, calculated rms angle jitter at system threshold is 0.4 mil, which generally agrees with measured values.

VI. Future Plans for Improvement

Extra-terrestrial radio communications has been demonstrated and practiced successfully by radio astronomers for many years. As a result of their pioneering effort, the job of communicating with rocket-launched space probes has been and will continue to be much less difficult. Utilization of their data, analyses, techniques and in some cases actual equipment designs made it possible to develop the TRAC(E) system in a very short period of time with sufficient long-term capabilities that it could communicate to the distance of the moon in 1958 and to the planets during the period 1960–1962. (See Table V.) A basic element of the TRAC(E) system, for example, is the 85-foot diameter antenna designed for radio astronomy research by the Blaw-Knox Company under an Associated Universities contract. With this antenna and the TRAC(E) receiver described in this report, it would be possible to communicate to the nearby planets. However, future plans are to extend the range (and/or the bandwidth) still further by the addition of low-noise amplifiers. An over-all noise temperature of 400°K is predicted for 1960 using a parametric amplifier, and a temperature of 40°K for 1962 using a maser.

The real significance of Table V is that the principal factors which are expected to extend the communicating range are related to the space vehicle. Over a period of four years, it is suggested that the vehicle transmitter power could be increased 27 db, from 200 mw to 100 watts, and the vehicle antenna gain could be increased 36 db. With these improvements, Table V shows that space communications could be maintained anywhere in the solar system with a bandwidth of 30 cps. Solution of these problems in the time scale indicated depends on many factors, such as vehicle performance, payload weight, primary power, earth-seeking vehicle antenna system, financial support, etc.

The present TRAC(E) system is a one-way link which measures two angles and one-way Doppler, and receives telemetry. Future TRAC(E) communications will be two-way, employing a 10-kw UHF ground transmitter and vehicle-borne transponder. The two-way TRAC(E) system will measure two angles, range and range-rate; it will receive telemetry and also provide a radio command link to the space vehicle.

Appendix

TRAC(E) Tracking Receiver Design Specifications for Pioneers III and IV

I. Frequency—nominal 960.05 mc (also see XII).

II. Noise Figure—7.5 db or less.

III. Bandwidth—20 cps at threshold.

IV. Threshold—154.1 dbm defined as the signal level at which the receiver loses lock.

V. Range of Input Signal Level— −45 dbm to threshold.

VI. RF Loop Characteristics

A. RF Loop Transfer Function

$$H(s) = \frac{1 + \frac{3}{4B_L} s}{1 + \frac{3}{4B_L} s + \frac{9}{32 B_L^2} s^2}$$

where

$$2B_L = \frac{1}{2\pi} \int_{-\infty}^{\infty} | H(j\omega) |^2 dw$$

$$= \frac{2}{3} B_{L_0}\left(1 + 2 \frac{a}{a_0}\right)$$

and

$$2B_{L_0} = 2\left(\frac{9}{32} \frac{G_0}{\tau_1}\right)^{1/2}$$

$\tau_1 = R_1C$,

G_0 = open-loop gain at threshold

$= 360 \times 30 \times k_m \times k_{\text{vcc}} \times \alpha_0$,

k_m = sensitivity of the RF phase detector in volts/degree

$= 0.7$ volt/degree,

k_{vco} = sensitivity of the RF VCO in cps/volt

$= 250$ cps/volt,

α_0 = signal suppression factor at threshold

$= 0.088$ for 20-cps bandwidth.

$$\alpha = \left[\frac{1}{1 + \operatorname{antilog}_{10}\left(\dfrac{1 + P_N - P_s}{10}\right)}\right]^{1/2}$$

$$= \left[\frac{1}{1 + \operatorname{antilog}_{10}\left(\dfrac{1 - 134.1 - P_s}{10}\right)}\right]^{1/2}$$

where

P_N = available noise power in the 455-kc IF amplifier 2-kc pass band (expressed in dbm)

k = Boltzman's Constant, 1.37×10^{-23} joule/°K

$= \log_{10}(kT_{\text{eff}}\Delta f \times 10^3) = -134.1$ dbm

P_s = available signal power in the same 2-kc bandwidth in the same units as P_N.

Consequently

$$H(s) = \frac{1 + \dfrac{1}{\lambda}s}{1 + \dfrac{1}{\lambda}s + \dfrac{1}{2\lambda^2}s^2}$$

where

$$\lambda = \frac{4}{9}B_{L_0}\left[1 + \frac{2}{\alpha_0}\,\frac{1}{1 + \operatorname{antilog}_{10}\left(\dfrac{1 - 134.1 - P_s}{10}\right)}\right]^{1/2}.$$

B. RF Loop Noise Bandwidth

1) Design Value at Design Threshold and Signal Frequency ($2B_{L_0} = 20$ cps)

2) Variation with Signal Level

The RF loop noise bandwidth shall vary from 20 cps at design threshold to 158 cps at strong signal levels ($\alpha = 1$).

3) Variation with Signal Frequency

The threshold RF loop noise bandwidth shall vary from 20 cps at design signal frequency to not less than 14.1 cps at signal frequencies displaced ±2.6 parts in 10^5 from the design signal frequency.

C. RF Loop Phase Error

1) Variation with Signal Input Frequency

The static phase error at threshold shall not exceed 6° at signal frequencies displaced ±2.75 parts in 10^6 from the design signal frequency. At these two frequency extremes, the threshold will be reduced 1 db from that specified at design signal frequency. Static phase error at strong signal levels ($\alpha = 1$) shall not exceed 13.5° at signal frequencies displaced ±2.6 parts in 10^5 from the design signal frequency.

2) Maximum Rate of Change of Input Signal Frequency

The phase error at threshold shall not exceed 6° for a maximum rate of change of 6 parts in 10^9 per second in input signal frequency. At this maximum rate, the threshold will be reduced 1 db relative to that obtained for a zero rate of change in signal frequency.

The phase error at strong signals ($\alpha = 1$) shall not exceed 30° for a maximum rate of change of 3.5 parts in 10^7 per second in input signal frequency.

3) RMS Phase Error

The RMS phase error due to noise shall not exceed 1.0 radian at design threshold. The RMS phase error due to noise shall not exceed 0.06 radian at an input signal level of −120 dbm.

4) Residual Phase Error

The residual phase error shall not exceed 3° peak at strong signal levels ($\alpha = 1$) within an RF loop noise bandwidth of 20 cps.

5) Noise Bias

The maximum phase error due to noise at threshold shall not exceed 1 per cent of the phase detector S curve amplitude at threshold (equivalent to static phase error of 0.6°).

VII. AGC Loop Characteristics (Coherent AGC)

A. AGC Loop Transfer Function

$$H(s) = \frac{1}{\left(1 + \dfrac{1}{G}\right) + \dfrac{\tau}{G}s}$$

where

τ = time constant of AGC filter

$= 300$ seconds

G = gain of the AGC loop

$= K_DK_A$

and

K_D = AGC detector constant expressed in volts/db

$= 3.1$ volts/db at threshold

$= 4.0$ volts/db at −45 dbm input signal level

K_A = constant associated with the gain of the receiver expressed in db/volt

$= 5$ db/volt at threshold

$= 17$ db/volt at −45 dbm input signal level.

B. AGC Loop Noise Bandwidth

1) Design Value at Design Threshold

$2B_L = 0.025$ cps

2) Variation with Signal Level

The AGC loop noise bandwidth shall vary from 0.025 cps at design threshold to 0.11 cps at an input signal level of −45 dbm.

C. AGC Loop Gain Error

1) Static Gain Error

The variation in coherent detected receiver output shall vary not more than 6 db for the range of input signal levels from −45 dbm to threshold.

2) Maximum Rate of Change of Input Signal Level

The gain error at threshold shall not exceed 1 db for a maximum rate of change of 0.05 db per second in input signal level. The gain error at an input signal level of −45 dbm shall not exceed 1 db for a maximum rate of 0.25 db per second in input signal level.

3) RMS Gain Error

RMS gain error introduced in the RF and angle tracking loops at threshold shall not exceed 0.1 db rms. RMS gain error at an input signal level of −120 dbm shall not exceed 0.003 db rms.

VIII. 30/31-mc Frequency Shifter Phase-Locked Loop Characteristics

A. Frequency Shifter Loop Transfer Function

$$H(s) = \frac{1 + \dfrac{3}{4B_L} s}{1 + \dfrac{3}{4B_L} s + \dfrac{9}{32B_L{}^2} s^2}$$

where

$$2B_L = 2\left(\frac{9G_0}{32\tau_1}\right)^{1/2}$$

$\tau_1 = R_1C$

$G = 360 \times 32 \times k_m \times k_{\text{vco}}$

k_m = sensitivity of the frequency shifter phase detector in volts/degree

= 0.25 volt/degree

k_{vco} = sensitivity of the frequency shifter VCO in cps/volt

= 45 cps/volt.

B. Frequency Shifter Loop Noise Bandwidth

1) Design Value at Design Frequency

$2B_L = 1340$ cps

2) Variation with Frequency

The frequency shifter loop noise bandwidth shall vary from 1340 cps at design frequency to not less than 950 cps at frequencies displaced ±3 parts in 10^5 from the design frequency.

C. Frequency Shifter Loop Phase Error

The static phase error shall not exceed 5° at frequencies displaced ±3 parts in 10^5 from the design frequency.

IX. 30.455-mc SSB Modulator Phase-Locked Loop Characteristics

A. SSB Modulator Loop Transfer Function

$$H(s) = \frac{1 + \dfrac{3}{4B_L} S}{1 + \dfrac{3}{4B_L} S + \dfrac{9}{32B_L{}^2} S^2}$$

where

$2B_L = 2(9/32\ G/\tau_1)^{1/2}$

$\tau_1 = R_1C$

$G = 360 \times K_m \times K_{\text{vco}}$

K_m = sensitivity of the SSB modulator phase detector in volts/degree

= 0.7 volt/degree

K_{vco} = sensitivity of the SSB modulator VCO in cps/volt

= 250 cps/volt.

B. SSB Modulator Loop Noise Bandwidth

1) Design Value at Design Frequency

$2B_L = 1200$ cps

2) Variation with Frequency

The SSB modulator loop noise bandwidth shall vary from 1200 cps at design frequency to not less than 850 cps at frequencies displaced ±3 parts in 10^5 from the design frequency.

C. SSB Modulator Loop Phase Error

The static phase error shall not exceed 10° at frequencies displaced ±3 parts in 10^5 from the design frequency.

X. Angle Error Channel Characteristics

A. Gain Tracking

The differential gain between either angle error channel and the reference channel shall not exceed 2 db over the range of input signal levels from −45 dbm to threshold. Gain tracking is determined by comparison of the coherent output signal levels in the angle error channel to the reference channel output.

B. Phase Tracking

The differential phase between either angle error channel and the reference channel shall not exceed ±10° over the range of input signal levels from −45 dbm to threshold. Phase tracking is determined by comparison of the phase of the coherent output signal level in the angle error channel to reference channel phase output.

C. RMS Angle Tracking Error

RMS angle tracking error in the 0.06 cps noise bandwidth of the angle tracking servosystem shall not exceed 0.022 rms at threshold.

XI. Modulation Characteristics

A. Amplitude Response and Phase Symmetry of 2-kc Pass Band

The amplitude characteristic of the 455-kc IF amplifier shall be flat to ±1.5 db within the 2-kc pass band. The phase characteristic of the 455-kc IF amplifier shall be symmetrical to within 45° about the center of the 2-kc pass band.

XII. Frequency—The nominal center frequency shall be 960.05 mc with the ability to track plus or minus 3.0 parts in 10^5 from the nominal center frequency. By changing the crystal and retuning the VCO, the center frequency can be changed between 955 mc and 965 mc.

XIII. Input VSWR—The input VSWR to the receiver shall be less than 1.5 to 1 for a 50-ohm transmission line.

XIV. Image Rejection—The image rejection of the receiver shall be at least 40 db.

XV. Telemetry Bandwidth—The narrowest bandwidth of the receiver before the telemetry output shall be 10 kc.

XVI. Residual Phase Modulation—The residual phase modulation in the RF loop when measured with a signal source at -60 dbm shall be less than 3° peak.

XVII. Internal Interference in the RF Loop—The internal interference in the RF loop due to coherent leakage signals of the receiver shall be at least 40 db below the signal level at threshold when the interference enters ahead of the limiter and at least 60 db below the signal level at threshold when the interference enters following the limiter.

XVIII. Internal Interference in the AGC Loop—The internal interference in the AGC loop due to coherent leakage signals of the receiver shall be at least 40 db below the signal level at threshold.

XIX. Internal Interference in the Angle Detector Channels—The internal interference in the angle detector channels due to coherent leakage signals of the receiver shall be at least 40 db below the signal level at threshold.

XX. Cross Coupling Between Channels—The signal isolation between any two channels shall be at least 60 db.

XXI. Receiver IF Frequencies—The receiver IF frequencies shall be 30 mc and 455 kc.

XXII. First Local Oscillator Frequency—The first local oscillator signal shall be derived from a 31-mc VCO which is frequency multiplied by 30.

XXIII. Coherent Local Oscillator Frequencies—The local oscillator signals shall be derived in such a manner that the received signal frequency can be determined by measurement of the 31-mc VCO frequency only.

XXIV. Recording Outputs—Provision shall be made for making the following available for recording:

receiver AGC,
RF loop dynamic phase error and telemetry,
telemetry subcarriers,
Doppler frequency plus constant frequency,
spin modulation,
declination error,
hour angle error.

Acknowledgment

The authors wish to acknowledge the efforts of all the Jet Propulsion Laboratory personnel whose teamwork contributed to successful radio frequency tracking and communication with the Pioneers III and IV space probes. They wish to express particular thanks to Dr. E. Rechtin and W. K. Victor of JPL under whose direction this effort was accomplished. Acknowledgment is also made to the Collins Radio Company, Cedar Rapids, Iowa, who provided assistance during the design, construction, and installation of the Goldstone Radio Tracking System.

Tracking and Display of Earth Satellites*

F. F. SLACK† AND A. A. SANDBERG†

Summary—**In a new method of displaying the predicted paths and real-time positions of artificial earth satellites, cathode-ray tubes are used with two types of map overlays: orthographic projection and Mercator projection. Functions to match these projections are generated electronically. Auxiliary satellite information is cataloged and made available through "light gun" interrogation of the satellites displayed on the CRT. The display and orbit simulator can be used as an integral part of a live tracking system.**

A mathematical derivation of the subsatellite path on the orthographic projection is given.

INTRODUCTION

ELEVEN man-made objects are now orbiting in space around the earth. In the foreseeable future, an increasing number of satellites will undoubtedly be placed in orbit. As the frequency of launchings increases, so does the need for a panoramic visual display of all satellite positions in space relative to the earth's surface.

The repetitive nature of the orbits and the stability of the paths of the satellites through space point to a simple and reasonably accurate method of display. In the method under development at the Astrosurveillance Sciences Laboratory of the Air Force Cambridge Research Center, electronic analog simulators are used to generate the functions representing the predicted satellite orbits. The paths are presented visually on the face of a large-screen cathode-ray tube (CRT), over which is overlaid a transparent map projection of the earth. The predicted paths are generated at a frequency high enough to prevent flickering when presentation is time-shared. The real-time positions of the satellite are displayed as intensified spots on their respective traces and travel at rates corresponding to the speeds of the satellites.

After orbital characteristics have been established, the simulators must permit updating of the orbital paths by more accurate position information obtained from periodic observation of the satellite itself.

The system is sufficiently flexible to allow time to be moved forward and backward, up to one week. The value of this feature becomes apparent from the nature of the corrections that are possible in the simulated orbit. Although very accurate measurements of the real orbits are available from sophisticated sources, the data take time to process, and arrive late. If the system is turned back to the time when the observation was made, it is possible to inspect the simulated orbit, make any necessary correction, and then return the system to the present time. On occasions when it is desirable to know the satellite situation at some time in the future—as, for instance, if it is important to know when a communication or surveillance satellite will be over a particular area of the earth—time can be advanced until the simulated satellite position coincides with the specified position on the map overlay. The date and time can then be read off the calibrated controls that advance the time.

Access to other pertinent satellite data is accomplished through interrogation of the display with a "light gun." This is a photocell device that produces a video signal when pointed at the real-time spot of light on the CRT. Coincidence between the video signal and an electronic gate representing the sequenced time slot for displaying that specific satellite actuates a relay. The relay then controls a number of indicator circuits that present cataloged information relevant to the interrogated satellite, including identification, distance of apogee and perigee, date of launching, type of scientific and/or military data transmitted from the satellite, and maximum and minimum speeds. The same relay also samples a "range from earth" potentiometer geared to track with the real-time position generator, one indicator thus providing altitude readings for all satellites.

THE SATELLITE DISPLAY

Any presentation of satellite orbital information is inherently limited by the difficulty of accurately displaying a spherical area on a flat surface. Regardless of the type of map projection used, distortion is inevitable in the scale, perspective, and shape of the orbit. The rather difficult task of minimizing distortion to maintain a comprehensible, three-dimensional presentation then becomes a problem of the technical feasibility of compensating for the distortion.

Recent advances in display techniques may lead to substantially larger presentations. The newly developed mosaic displays that use gaseous, chemical, or electroluminescent cells have possibilities. A cathode-ray tube having a spherical screen—if it could be designed—would present the most realistic picture, but most requirements can be satisfied if the CRT has a hemispherical screen, which can be designed. To avoid delaying the display program, the present models are being designed around large-screen flat-faced CRT's because of their availability and standard deflection requirements.

A system of time-sharing shows all orbits in sequence above the CRT flicker rate. To display the predicted paths in time sequence, periodic functions that match the map projection are generated at a 5-kc frequency. This allows 100 targets to be displayed at a 50-cps rate.

The system's accuracy is governed primarily by the CRT and deflection system used in the display. Experi-

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* Original manuscript received by the IRE, November 23, 1959.

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ence has shown that in a conventional CRT and deflection system, errors can be held under 0.33 per cent. Analog techniques should therefore satisfy the accuracy requirements of the complete system. If the combined errors of the display and function generators are not greater than 0.5 per cent, positions on the earth traversed by the satellite will be displayed within 125 miles, corresponding to 36 seconds of orbit time for a 2-hour orbit. This accuracy should be adequate for most applications, since a satellite orbiting at an altitude of 1000 miles can theoretically be seen by a line-of-sight detector 3000 miles from the detection location.

Two different types of map projections are used in the displays currently under development in the Laboratory: orthographic and Mercator.

THE ORTHOGRAPHIC PROJECTION

In the orthographic projection (perspective of the earth from infinity), the map overlay on the CRT is a hemisphere; two displays show the total earth. On this presentation, an orbital path projected onto a stationary earth (earth not rotating on its axis) appears as a portion of an ellipse. To show predicted paths relative to the earth's surface (Fig. 1), electronic function generators compensate for the distortion that the earth's rotation causes in the presentation of the elliptic pattern. For a polar projection, the sine and cosine functions of two oscillators of slightly different frequencies provide an electronic analog that satisfies the mathematical expressions.

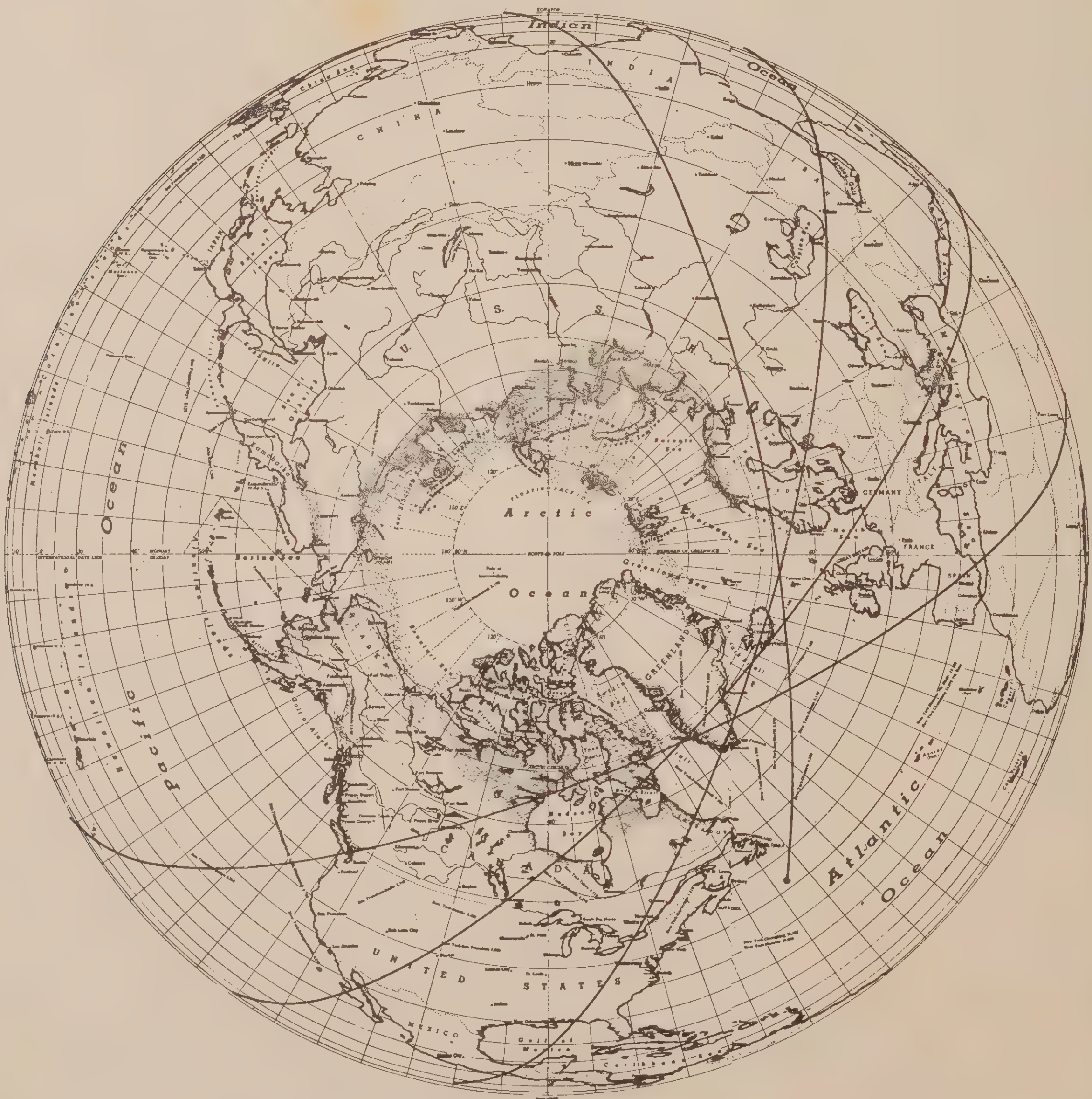
Indian
Ocean
INDIA
CHINA
U. S. S. R.
Arctic
Ocean
NORTH POLE
Bering Sea
Barents Sea
Norwegian Sea
Greenland Sea
GREENLAND
GERMANY
FRANCE
SPAIN
Pacific
Ocean
Atlantic
Ocean
CANADA
UNITED STATES
MEXICO
Gulf of Mexico
Caribbean Sea

Fig. 1—Several orbits of an artificial earth satellite on an orthographic polar projection showing precessing due to earth's rotation.

Displayed on a CRT, the functions trace out the predicted path of the satellite. Each successive trace, in speeded-up time, precesses the same number of degrees that the earth will rotate under each successive satellite orbit.

The real-time motion and position of the satellite orbit is generated by a computer driven by a clock motor in real time. Sine and cosine potentiometers rotating at slightly different rates perform the same role as the electronic oscillators. The real-time position of the satellite is established on the display by repeatedly locking the start of the predicted trace to the x, y positions as determined by the real-time computer.

The locking gate can be manually controlled to show the predicted path of the satellite anywhere from zero time to several orbits. The CRT beam is held momentarily at the beginning of the sweep, thereby intensifying the real-time position of the satellite.

A MATHEMATICAL DERIVATION OF AN ORTHOGRAPHIC SUBSATELLITE TRACK

The following exercise shows the derivation of the mathematical equations of motion for the subsatellite track (projection of the orbit onto the earth's surface) to 1.0 per cent accuracy on an orthographic map projection.

The known equations of motion of a satellite in a plane are transformed to the equations of motion of a satellite in three dimensions with respect to axes fixed to the earth. As a final step, the equations of motion in three dimensions are converted to the subsatellite position as a function of time.

The mathematical exercise consists of the following steps:

1) The equations of motion for a set of axes whose x member coincides with the semimajor axis of the satellite's elliptic path are transformed to a new set of axes in the same orbital plane *but whose x member, instead of passing through the perigee, is so oriented as to pass through the point of maximum latitude of the orbit.* (The point of maximum latitude is shown in Fig. 4 as point M.)
2) The equations of motion are then referred to a set of axes that are fixed in space. The x and y members are in the plane of the earth's equator, with the z member perpendicular to the equatorial plane.
3) The equations of motion for a rotating system fixed to the earth are obtained. The result represents the position of the satellite in three-dimensional space, given in Cartesian coordinates as a function of time.
4) As a final step, the result is transformed to project the actual path in space onto the earth, thus forming the subsatellite equations of motion.

The following notation will apply in this section:

a = semimajor axis of ellipse
e = eccentricity of ellipse
i = orbit inclination to the equatorial plane
s = angular frequency of satellite ($2\pi/T_s$)
ω = argument of perigee
ω_e = angular frequency of earth's rotation ($2\pi/T_e$)
T_e = period of earth's rotation
T_p = time of perigee crossing
T_s = period of satellite
$E = s(t-T_p) + e \sin s(t-T_p) + e^2/2! \sin 2s(t-T_p) + \cdots$.

Equations of Motion

The path of a point mass moving in an inverse-square central force field is a conic section. Under the conditions assumed here, it will be an ellipse of low eccentricity (Fig. 2), one of whose foci is the center of the central force field (in this case the center of the earth).

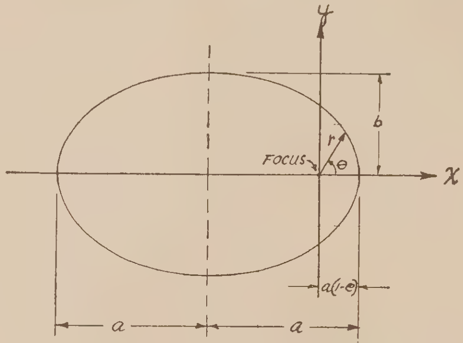

Fig. 2—Geometry of elliptic orbit. a = semimajor axis, b = semiminor axis, e = eccentricity

$$e = \frac{\sqrt{a^2 - b^2}}{a}.$$

According to Moulton, the path has the mathematical expression

$$r = \frac{a(1 - e^2)}{1 + e\cos\theta}. \tag{1}$$

Eq. (1) is an expression for the path, but what is required is a parametric representation, $y = y(t)$ and $x = x(t)$. The exact solution of this problem is, in general, impossible to obtain in closed form. The following equations are derived from Moulton:[1]

$$x = a(\cos E - e),$$
$$y = \sqrt{1 - e^2} \sin E. \tag{2}$$

If $e \leq 0.1$, only the first two terms of the infinite series for E are required to insure better than 1 per cent accuracy in $\sin E$ and $\cos E$ terms.

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[1] F. R. Moulton, "An Introduction to Celestial Mechanics," The Macmillan Co., New York, N. Y., pp. 164–165; 1947.

Transformation I

Transformation I is illustrated in Fig. 3. The orientation of the coordinate system with respect to the earth is given in Fig. 4.

Elementary coordinate transformations give the following relationships between the x, y coordinate system and the x', y' coordinate system. (Note that $z \equiv Z' \equiv 0$, the satellite being assumed to move in the x, y or x', y' plane.)

$$x' = x \cos\beta + y \sin\beta;$$
$$y' = -x \sin\beta + y \cos\beta. \qquad (3)$$

Since $\omega = 90° - \beta$, (3) can be rewritten as

$$x' = x \sin\omega + y \cos\omega;$$
$$y' = -x \cos\omega + y \sin\omega. \qquad (4)$$

For this analysis, ω is assumed constant, even though perturbation effects cause the ellipse to precess slightly.

Transformation II

Transformation II yields the equations of motion with respect to a set of axes fixed in space, with x and y members in the equatorial plane. Note that the mathematical rotation of axes is around the y' axis, thus making $y' \equiv y''$ (Fig. 5).

Elementary coordinate transformation equations give

$$x'' = x' \cos i - z' \sin i,$$
$$y'' \equiv y',$$
$$z'' = x' \sin i + z' \cos i. \qquad (5)$$

Transformation III

The system of coordinates x'', y'', z'' is now referred to a rotating earth. The coordinate system designated by x''', y''', z''' represents the satellite position in space. Transformation III (Fig. 6) gives

$$x''' = x'' \cos(\gamma + \omega_e t) + y'' \sin(\gamma + \omega_e t),$$
$$y''' = -x'' \sin(\gamma + \omega_e t) + y'' \cos(\gamma + \omega_e)t,$$
$$z''' \equiv z''. \qquad (6)$$

Solving (2) through (6) simultaneously for x''', y''', and z''' gives

$$x''' = A \cos(E + \omega_e t + \theta) + B \cos(E - \omega_e t + \phi) + C \cos(\omega_e t + \psi),$$
$$y''' = D \cos(E + \omega_e t + \delta) + F \cos(E - \omega_e t + \alpha) + G \cos(\omega_e t + \rho),$$
$$z''' = H \cos(E + \tau) - e k_5; \qquad (7)$$

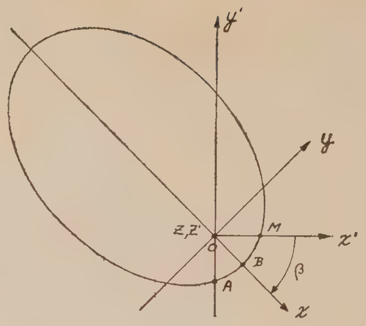

Fig. 3—Transformation I. Z and Z' are perpendicular to the page, directed positively outward.

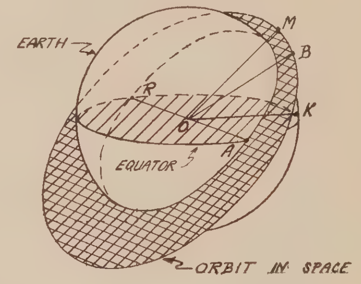

Fig. 4—Orientation of coordinate system in Fig. 3. M = point of maximum latitude, B = perigee, K = point on equator, the same longitude as point M, β = angle MOB, ω = argument of perigee angle BOA, angle MOA is 90°, angle β is $90° - \omega$, i = inclination of orbit to equator, angle MOK.

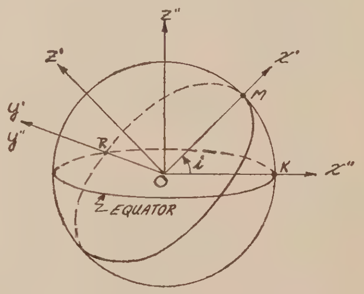

Fig. 5—Rotation of axes by Transformation II. $Z' \perp x'$ and y'. i = inclination of orbit.

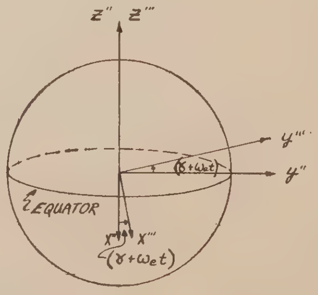

Fig. 6—Transformation III. x'' and y'' are in the plane of the equator but fixed in space. x''' and y''' are in the plane of the equator but fixed to earth.

where

$$A=\tfrac{1}{2}\sqrt{(k_1-k_4)^2+(k_2-k_3)^2}, \qquad \theta=\gamma-\tan^{-1}\frac{(k_2-k_3)}{(k_1-k_4)};$$

$$B=\tfrac{1}{2}\sqrt{(k_1+k_4)^2+(k_3+k_2)^2}, \qquad \phi=\gamma-\tan^{-1}\frac{(k_3+k_2)}{(k_1+k_4)};$$

$$C=\tfrac{e}{2}\sqrt{(k_3)^2+(k_1)^2}, \qquad \psi=\gamma-\tan^{-1}\frac{(k_3)}{(-k_1)};$$

$$D=\tfrac{1}{2}\sqrt{(k_2-k_3)^2+(k_4-k_1)^2} \qquad \delta=\gamma-\tan^{-1}\frac{(k_4-k_1)}{(k_2-k_3)};$$

$$F=\tfrac{1}{2}\sqrt{(k_2+k_3)^2+(k_4+k_1)^2}, \qquad \alpha=\gamma-\tan^{-1}\frac{(k_4+k_1)}{-(k_2+k_3)};$$

$$G=e\sqrt{(k_3)^2+(k_1)^2}, \qquad \rho=\gamma-\tan^{-1}\frac{(k_3)}{(k_2)};$$

$$H=\sqrt{(k_5)^2+(k_6)^2}, \qquad \tau=-\tan^{-1}\frac{(k_6)}{(k_5)}; \tag{8}$$

where

$$k_1 = a\sin\omega\cos i; \qquad k_2 = a\sqrt{1-e^2}\cos\omega\cos i;$$

$$k_3 = a\cos\omega; \qquad k_4 = a\sqrt{1-e^2}\sin\omega;$$

$$k_5 = a\sin\omega\sin i; \qquad k_6 = a\sqrt{1-e^2}\cos\omega\sin i. \tag{9}$$

Transformation IV

With the equations of motion in three-dimensional space determined, it is now necessary to transform these relations to the equations of motion of the subsatellite track, in a form amenable to electronic simulation. Transformation IV is illustrated in Fig. 7. The coordinates of the subsatellite track are

$$x_{ss} = \frac{R}{r}x'''; \qquad y_{ss} = \frac{R}{r}y'''; \qquad z_{ss} = \frac{R}{r}z'''. \tag{10}$$

Solving for x_{ss}, using Moulton's equation $r=a(1-e\cos E)$, gives

$$x_{ss} = \frac{Rx'''}{a(1-e\cos E)}. \tag{11}$$

If $e\leq 0.1$, (11) may be approximated with only the first two terms of the Taylor series, as

$$x_{ss} \approx \frac{R}{a}(1+e\cos E)x'''. \tag{12}$$

Substituting the expression for x''' in (7) into (12) gives

$$x_{ss} = \frac{R}{a}(1+e\cos E)\big[A\cos(E+\omega_e t+\theta) + B\cos(E-\omega_e t+\phi)+C\cos(\omega_e t+\psi)\big]. \tag{13}$$

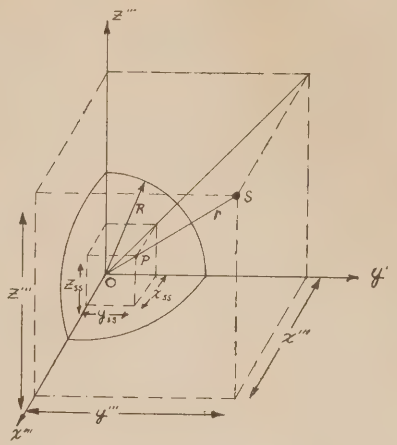

Fig. 7—Transformation IV. r is the distance of the satellite from the center of the earth, R is the radius of the earth and P is the projection of the satellite (s) onto the earth.

Multiplied out,

$$\begin{aligned} x_{ss} = {} & \frac{R}{a}\big[A\cos(E+\omega_e t+\theta)+B\cos(E-\omega_e t+\phi) \\ & +C\cos(\omega_e t+\psi)\big]+\frac{Re}{a}\big[A\cos E\cos(E+\omega_e t+\theta) \\ & +B\cos E\cos(E-\omega_e t+\phi) \\ & +C\cos E\cos(\omega_e t+\psi)\big]. \end{aligned} \tag{14}$$

The approximation

$$E = s(t-T_p)+e\sin s(t-T_p) \tag{15}$$

for $e\leq 0.1$ per cent, produces errors not greater than 1 per cent in sin E and cos E terms.

Assuming that errors no greater than 1 per cent can be tolerated (15), various trigonometric relations, and approximations based on a Taylor series, can be used to reduce (14) to

$$\begin{aligned} x_{ss} = \frac{R}{a}\Big\{ & A\cos\big[(s+\omega_e)t+\theta-sT_p\big] \\ & +B\cos\big[(s-\omega_e)t+\phi-sT_p\big] \\ & +eA\cos\big[(2s+\omega_e)t+\theta-2sT_p\big] \\ & +eB\cos\big[(2s-\omega_e)t+\phi-2sT_p\big] \\ & +C\cos(\omega_e t+\psi)\Big\}. \end{aligned} \tag{16}$$

To calculate y_{ss}, it is not necessary to carry out the full procedure used in solving for x_{ss}, but merely to determine how x''' and y''' are related. Inspection shows that when

$$x_{ss}\rightarrow y_{ss}, \qquad x''\rightarrow y''';$$

$$A\rightarrow D, \qquad B\rightarrow F, \qquad C\rightarrow G;$$

$$\theta\rightarrow\delta, \qquad \phi\rightarrow\alpha, \qquad \psi\rightarrow\rho.$$

Therefore,

$$\begin{aligned} y_{ss} = \frac{R}{a} & D \cos \left[(s + \omega_e)t + (\delta - sT_p)\right] \\ & + F \cos \left[(s - \omega_e)t + (\alpha - sT_p)\right] \\ & + De \cos \left[(2s + \omega_e)t + (\delta - 2sT_p)\right] \\ & + Fe \cos \left[(2s - \omega_e)t + (\alpha - 2sT_p)\right] \\ & + G \cos (\omega_e t + \rho) \big\}. \qquad (17) \end{aligned}$$

To solve for z_{ss}, the procedure is the same as for x_{ss}. Thus,

$$z_{ss} = \frac{Rz'''}{a(1 - e \cos E)} \approx \frac{R}{a}(1 + e \cos E)z'''. \qquad (18)$$

Substituting from (7), (18) gives

$$z_{ss} = \frac{R}{a}(1 + e \cos E)\left[H \cos (E + \tau) - ek_5\right]. \qquad (19)$$

Simplifying, as in the case of x_{ss}, gives

$$\begin{aligned} z_{ss} = \frac{R}{a} & \big\{H \cos \left[s(t - T_p) + \tau\right] \\ & + eH \cos \left[2s(t - T_p) + \tau\right] - ek_5\big\}. \qquad (20) \end{aligned}$$

Circular Orbit, a Special Case

For a circular orbit $e = 0$, the equations become greatly simplified. Where r is the radius of the orbit,

$$\begin{aligned} x_{ss} &= \frac{R}{r}\big\{A \cos \left[(s + \omega_e)t + \theta - sT_p\right] \\ & \quad + B \cos \left[(s - \omega_e)t + \phi - sT_p\right]\big\}; \\ y_{ss} &= \frac{R}{r}\big\{D \cos \left[(s + \omega_e)t + \delta - sT_p\right] \\ & \quad + F \cos \left[(s - \omega_e)t + \alpha - sT_p\right]\big\}; \\ z_{ss} &= \frac{R}{r}\big\{H \cos \left[s(t - T_p) + \tau\right]\big\}. \qquad (21) \end{aligned}$$

To consider a specific case, assume that $\omega = 0$, $T_p = 0$, and $\gamma = 0$. Then

$$k_1 = k_4 = k_5 = 0,$$

$$k_2 = r \cos i, \qquad k_3 = r, \qquad k_6 = r \sin i;$$

and

$$A = \frac{r}{2}(1 - \cos i) = r \sin^2\left(\frac{i}{2}\right),$$

$$B = \frac{r}{2}(1 + \cos i) = r \cos^2\left(\frac{i}{2}\right),$$

$$C = 0,\ D = A,\ F = B,\ G = 0,\ H = r \sin i;$$

$$\theta = -90°,\ \phi = -90°,\ \psi = +90°,\ \delta = 0,$$

$$\alpha = 0,\ \rho = -90°,\ \tau = -90°.$$

Substituting these values in (21) gives

$$\begin{aligned} x_{ss} &= R\left\{\sin^2\left(\frac{i}{2}\right) \cos \left[(s + \omega_e)t - 90°\right] \right. \\ & \qquad \left. + \cos^2\left(\frac{i}{2}\right) \cos \left[(s - \omega_e)t - 90°\right]\right\}, \\ y_{ss} &= R\left\{\sin^2\left(\frac{i}{2}\right) \cos \left[(s + \omega_e)t\right] \right. \\ & \qquad \left. + \cos^2\left(\frac{i}{2}\right) \cos (s - \omega_e)t\right\}, \\ z_{ss} &= (R \sin i) \cos (st - 90°); \qquad (22) \end{aligned}$$

or,

$$\begin{aligned} x_{ss} &= R\left\{\sin^2\left(\frac{i}{2}\right) \sin \left[(s + \omega_e)t\right] \right. \\ & \qquad \left. + \cos^2\left(\frac{i}{2}\right) \sin (s - \omega_e)t\right\}, \\ y_{ss} &= R\left\{\sin^2\left(\frac{i}{2}\right) \cos \left[(s + \omega_e)t\right] \right. \\ & \qquad \left. + \cos^2\left(\frac{i}{2}\right) \cos (s - \omega_e)t\right\}, \\ z_{ss} &= (R \sin i) \sin st. \end{aligned}$$

It is evident that three frequencies must be generated to simulate a circular orbit; for a polar projection (one of the poles in the center of the display), only two frequencies are required.

For the special case where $i = 0$, the equations reveal what is intuitively apparent: $z_{ss} = 0$, meaning that the simulated satellite is moving along the equator and travels with an angular velocity equal to the difference between the satellite's angular velocity and the earth's angular velocity.

Another very interesting case is that of the 24-hour communications satellite, for which $\omega_e = s$. For $i = 0$, it is apparent that $x_{ss} = \text{constant}$, $y_{ss} = \text{constant}$, and $z_{ss} = 0$. Because of the particular choice of ω and γ, $x_{ss} = 0$, $y_{ss} = R$. An additional modification of this case is when $i \neq 0$. Inspection of the z_{ss} and x_{ss} axes reveals that $z_{ss}(t)$ and $x_{ss}(t)$ are parametric equations for a figure-eight Lissajous pattern.

The foregoing exercise has demonstrated the derivation of the equations of motion of the subsatellite track as explicit functions of time and known constants of the orbit. It must be remembered, however, that the results are only approximate to within 1 per cent for satellites with eccentricity not greater than 0.1. For satellites of higher eccentricity, the mathematical analysis is much more complex and does not appear to be amenable to a practical direct electrical analog simulation. It may be possible to cancel some of this complexity through special electronic function generators designed for curve-fitting.

THE MERCATOR PROJECTION

In the second display method, a Mercator map projection presents the earth's geographic coordinates as an x, y grid. This projection can display the total area of the earth and has, therefore, been used extensively for plotting satellite courses (Fig. 11).

A Mercator projection spreads the area at the 80th parallel so that the east-west direction near the poles has the same dimension as the east-west direction at the equator. The system consequently produces a continually varying mileage scale, a land mass the size of Greenland seeming to have approximately the same area as South America. Because of this distortion, the electronic display voltages produced by the simulated-orbit generators are not amenable to a reasonable mathematical derivation. A great circle (circular orbit) *on* the equator appears as a straight line traveling east and west. Great circles *close* to the equator appear as sinusoids which have progressively larger amplitude and distortion the farther north and south they go. As the orbit approaches either pole, the sinusoid flattens off. A great circle that goes through the poles must travel parallel to the longitudinal lines and so appears as a square wave.

The orbits of most of the earth-circling satellites launched to date can be simulated for display on the Mercator projection by sine waves modified in a diode function generator, but the orbit of Explorer VI, launched in August, 1959, requires a different approach. The path of this orbit, although elliptic in space, takes on a peculiar shape when presented on a Mercator projection (Fig. 8). This irregularity is due to the relation between the satellite's speed and the earth's rotational speed. At perigee, approximately 260 km from earth, the satellite's speed is approximately 23,000 mph. As the satellite coasts out to apogee, 42,000 km away, it slows down to 2200 mph. Since any point on the earth at the equator is traveling at a constant 1000 mph, Explorer VI's east-west speed component projected onto the earth is sometimes faster and sometimes slower than the earth's rotational speed.

In a plot of the satellite course $y=f(x)$ on a Mercator map (Cartesian coordinate system), there are segments where y is a multivalued function of x. Since the x coordinate represents display time on the CRT, and the spot cannot be in more than one position at one time, the original deflection circuit had to be revised. The curve can be represented by two parametric equations $y=f_1(t)$; $x=f_2(t)$. Then x and y are single-valued functions of time that can be simulated in electronic function generators and applied to the x, y deflection circuit of the CRT (Fig. 9). The beam of the CRT traces out the desired function, and time is measured along the trace.

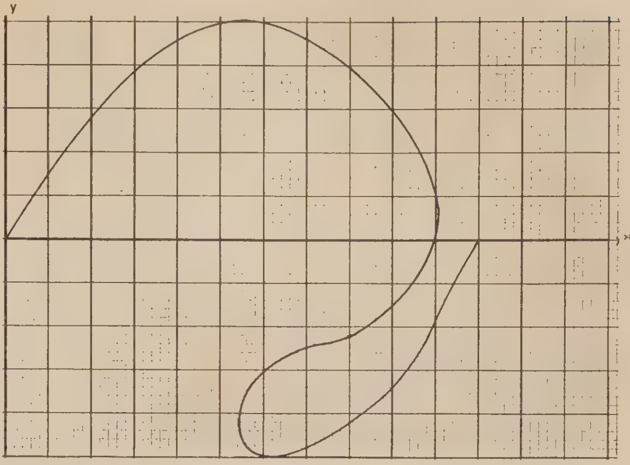

Fig. 8—Path of Explorer VI satellite on a Mercator projection. Note that y is a multivalued function of x (display time).

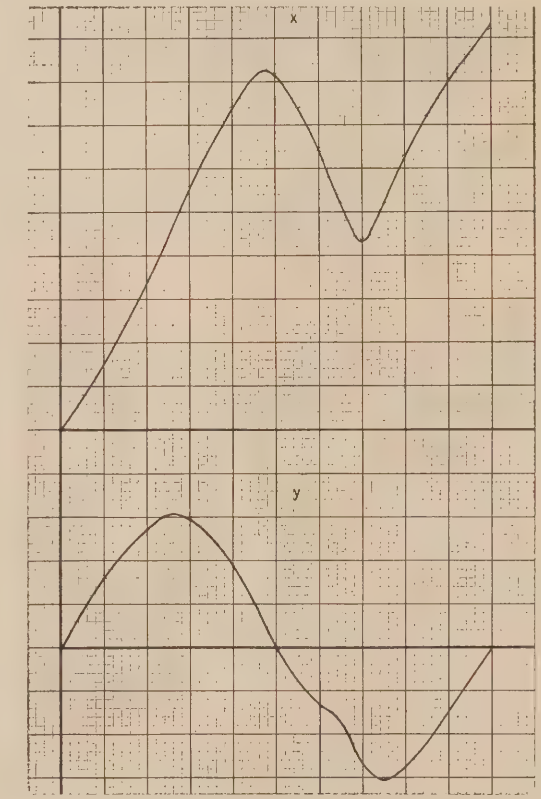

Fig. 9—Explorer VI orbit represented by two parametric curves $y=f_1(t)$; $x=f_2(t)$.

Bright spots moving along the predicted paths indicate the positions of the satellites in real time. The motion of the satellites is generated electromechanically, with a synchronous motor driving adjustable speed reducers coupled to potentiometers to produce the proper orbits as slowly varying dc voltages. The dc voltages are compared with linear sawteeth produced in the 5-kc time slots allotted to the respective orbits (see Fig. 10).

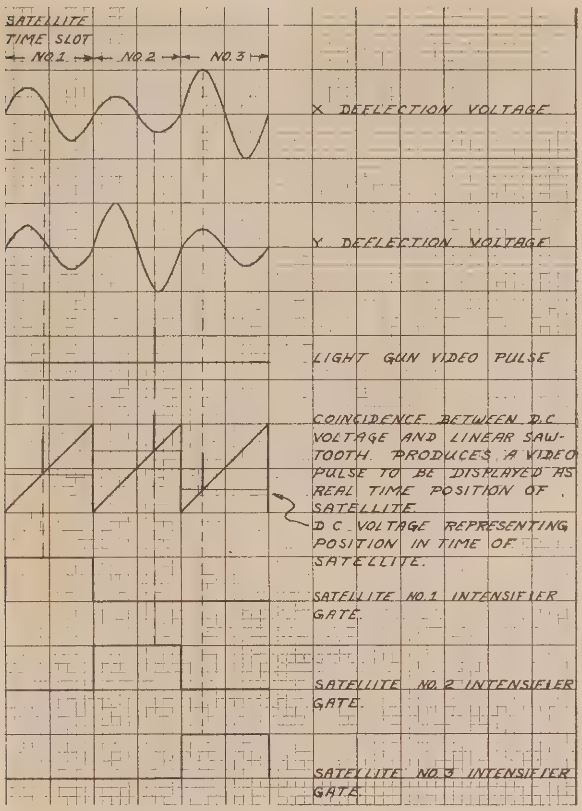
SATELLITE TIME SLOT
NO.1
NO.2
NO.3
X DEFLECTION VOLTAGE
Y DEFLECTION VOLTAGE
LIGHT GUN VIDEO PULSE
COINCIDENCE BETWEEN D.C. VOLTAGE AND LINEAR SAW-TOOTH. PRODUCES A VIDEO PULSE TO BE DISPLAYED AS REAL TIME POSITION OF SATELLITE.
D C. VOLTAGE REPRESENTING POSITION IN TIME OF SATELLITE.
SATELLITE NO.1 INTENSIFIER GATE.
SATELLITE NO.2 INTENSIFIER GATE.
SATELLITE NO.3 INTENSIFIER GATE.

Fig. 10—Cathode-ray tube timing waveforms.

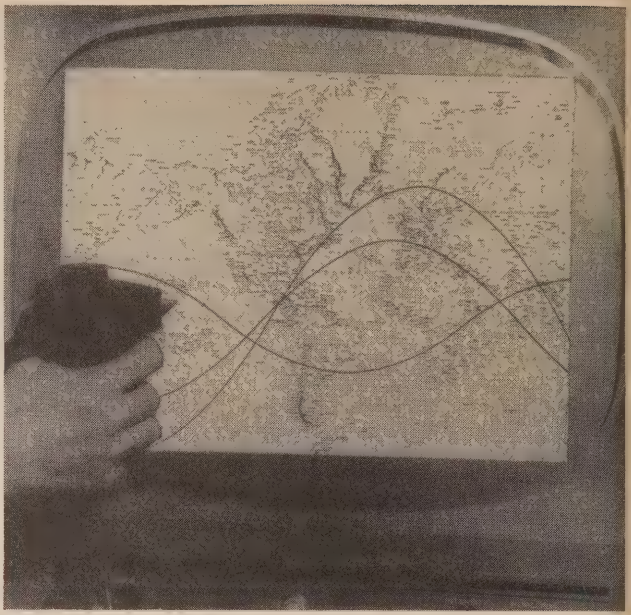

Fig. 11—"Light gun" interrogating satellite displayed as a bright spot on CRT trace with Mercator overlay.

Coincidence between a sawtooth voltage and a dc voltage generates a video timing pulse that is displayed as a bright spot (Fig. 11) on the trace of the orbit and indicates the instantaneous position of the satellite.

Since the speed of any satellite in a noncircular orbit is continually varying, maximum at perigee and minimum at apogee, accommodation for the changing speeds is provided through a suitable cam in the mechanical portion of the real-time position generator.

Because precessing of the orbit projected onto the earth is a function of the satellite's orbital frequency in relation to the earth's rotational frequency, it must be individually compensated for in each case. When the real-time position has completed 360° on the Mercator projection, the predicted trace is shifted the appropriate number of degrees for the start of the next cycle. This is accomplished by automatic shifting of a timing gate that selects the phase of the x, y functions to be displayed and clamps them to the proper starting voltage.

Display of Height Information

Height, the third component, is programmed into the simulator and made available on command. For each satellite, a linear height potentiometer mechanically tracks the real-time position. A removable cam mechanically linked to the potentiometer provides a function that converts the linear voltage to the actual height voltage. A digital voltmeter can be automatically connected to read the instantaneous height of any satellite interrogated by the light gun. When the height profile has changed sufficiently to warrant it, a new cam is inserted to make the readings more accurate.

The deviation of the earth's shape from a true sphere produces two additional effects that influence tracking and display: one, a slight precession of the orbit in the direction of the earth's rotation; the other, a similarly small precession of the orbit in its own plane. In other words, the apogee and perigee are continually rotating. These are minor perturbations of a few degrees per day, but they must be compensated for in the timing mechanism.

Because the timing of the complete system is controlled by a clock, it is possible to turn time backward and forward and inspect the satellite situation in the past and future as well as in the present.

Display of Auxiliary Information

Auxiliary satellite data can be stored in several ways. One would be to use recorded voice, with a separate channel for each satellite. Another would be to use a film that would project the information onto a screen. The simplest way, adequate for the present, is the use of identification lights that, when activated, refer to a file card on which the information is typed.

Access to the information is by means of a "light gun" (Fig. 11). This technique utilizes correlation between the time-sequenced voltage waveforms generated for displaying the positions of satellites and the pulse generated by the light gun when it is pointed at the satellite's position on the CRT. Coincidence between the two signals activates a relay that initiates the display action dictated by the particular storage scheme used. The following satellite information is cataloged:

1) identification,
2) date and time of launching,
3) size and weight,
4) height of apogee and perigee,
5) maximum and minimum speed,
6) inclination of orbit to equator,
7) type of scientific and/or military data transmitted from satellite,
8) pertinent ancillary information.

In addition to interrogating targets on the display, it is possible to locate the track and position of any specific satellite by operating an identification switch on the panel. This action intensifies the trace of that particular orbit, thereby distinguishing it from the others. Through control switches, it is also possible to select the orbits to be displayed. In the future, when the number of satellites has increased to the point where displaying them all at once might not be feasible, it may be desirable to select satellites for display according to category, such as communications, weather, or surveillance.

Simulator Used as an Automatic Tracking System

Future developments will include the capability of making automatic corrections in the simulated orbits from live data at the detection sites. Receiving periodic corrections on all satellites, the unit could be considered an important component in a live satellite detection and tracking system.

Since the electronic function generators scan all positions of the satellites as represented on the map overlay, it is possible to sample the functions with the real-time position video signals and store the instantaneous position voltages on capacitors. The stored dc voltages would represent the latitudes and longitudes of each satellite. With appropriate gating circuits allowing the generated functions of each satellite orbit to be corrected only by the live data representing their respective satellites, the device remotely resembles a track-while-scan unit used in radar systems. Application of this technique to the automatic tracking of satellites is possible because of the repetitive nature and stability of the orbits in space.

Acknowledgment

The authors wish to thank M. Mellow, G. Reppucci, and C. Forsberg for their valuable assistance in the design and development of the electronic equipment, and for their diligent effort in conducting experiments and collecting and assembling data.

They also express their gratitude to B. S. Karasik, technical editor, for her assistance in preparing this paper.

The Navy Space Surveillance System*

R. L. EASTON†, MEMBER, IRE, AND J. J. FLEMING†, MEMBER, IRE

Summary—A complete system for satellite detection and tracking and for computations of satellite orbits has been built by the Navy under ARPA sponsorship. This detection system uses a CW transmitter separated from two receiving sites, all having fan-type coplanar antenna beams. The angle of arrival of the reflected signals is measured at each station by the use of an interferometer. The position of the reflecting object is inferred by the point in the fan antenna beam defined by the intersection of the arrival angles at the two receiving stations.

Two ARPA-sponsored Space Surveillance radal (radio detection and location) devices of the type described have been installed in the southern U. S. In addition to the detecting and tracking installation the system includes data transmission lines, a data reduction center, a very high speed computer for orbit determination and predictions, and display devices.

Introduction

THE PROBLEM of detecting satellites is made difficult by their great height and velocity, and small size. The high velocity implies a short observation time but also implies great trajectory stability, so that a small number of independent observations properly separated on the ellipse serves to determine the orbit. The problem of detecting satellites is much different from that of tracking aircraft and ships for which the pulse radar was designed. For this earlier problem the target can maneuver rapidly and therefore required continuous tracking.

The detection system is shown schematically in Fig. 1. Here a transmitter antenna provides illumination in a narrow fan beam which is coplanar with similar re-

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* Original manuscript received by the IRE, December 2, 1959.
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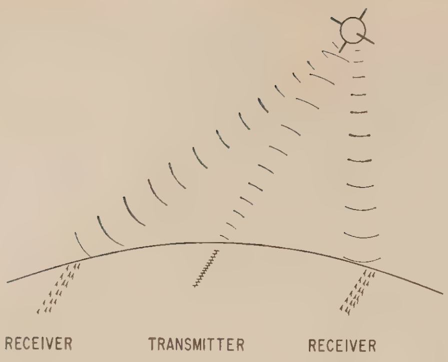

Fig. 1—The detection system used for space surveillance.

ceiving station beams. (Only that portion of the fan beam striking the satellite is shown in the figure.) The position of a reflecting object in the common antenna patterns is inferred by measuring the angle of reception of the reflected signals by means of interferometers at the two receiving sites.

The operation of the receiving stations is similar to that used by the system known as Minitrack[1] initiated by M. Rosen for use with Project Vanguard. The technique he suggested was similar to that used by several missile tracking systems, by radio astronomers, and by sonar. Minitrack was based largely on the missile tracking system AZUSA, built by the Convair Division of the General Dynamics Corporation. The operational principles of both systems appear to have been first conceived by Dr. H. L. Saxton of this Laboratory.[2]

Another contribution was made by Dr. J. J. Freeman[3] who analyzed this particular type of system. From his analysis it was simple to show that an interferometer system operating at a frequency of about 100 mc would require a radiated power of only a few milliwatts.

One of the problems existing in such a system is that of calibrating the angle measured electrically to the local zenith angle. Two techniques were implemented to provide the required calibration. One, involving ballistic camera photography of an airplane-carried flashing light, was demonstrated as practical by E. Habib, then of this Laboratory, and has been used as the standard calibration method for this system. The other method involved reflecting a signal off the moon. Then by knowing the local zenith angles of the moon and the corresponding electrical readings the required calibration was obtained, though with an accuracy much reduced from that obtainable with the ballistic camera.

The moon reflecting system consisted of a 50-kw FM transmitter installed to operate into a 50-ft dish at the Signal Corps Engineering Laboratories (now USARDL) at Ft. Monmouth, N. J. The transmitter was located and the work of the two laboratories was coordinated through the good offices of Lt. Col. E. J. Hagerman, Signal Corp Liaison Officer at the Naval Research Laboratory.

The moon reflection system was placed in operation in December, 1957. Early in 1958 the transmitter at SCEL was used to provide reflected signals from the remaining Sputnik (1957 Beta) into the tracking station at Blossom Point, Md., as shown in Fig. 2.

On June 20, 1958, the Advanced Research Projects Agency of the Department of Defense authorized the Naval Research Laboratory to provide one tracking complex in the Eastern United States and one in the Western United States as shown in Fig. 3. The NRL system is being expanded to form a continuous line across the Southern United States.

The first portion of the system to be placed in operation involved the stations at Fort Stewart, Ga., and Jordan Lake, Ala. This portion of the system was put in operation on July 29, 1958—less than six weeks after the ARPA Order was issued. This schedule was met by transporting the transmitter from SCEL to Jordan Lake and by modifying the Fort Stewart Minitrack station antennas to be compatible with this new system.

The Silver Lake installation became operational in November, 1958 and the Western Complex in February, 1959. The electronic equipment was built by Bendix Radio, the antennas by the Technical Appliance Company, and the transmitters were furnished by Multronics, Inc. The stations are operated by Bendix Field Operations Personnel.

The Receiving System

The receiving system has been described previously[1] so it will be discussed only briefly. Fig. 4 shows the principle of operation. After the signals from the two antennas are first amplified by preamplifiers, the output can be divided as necessary for the various phase comparisons required. By means of local oscillator circuits, the signals from the two antennas can be amplified in a single channel, thereby reducing the differential phase shift. When the combined signal is detected and compared to the difference frequency, the resulting phase is equal to the phase difference between the signals arriving at the two antennas. The zero reading of the phase between the two signals will not normally read zero for an equal phase signal at the antenna. The difference between the phase read and the phase present at the antennas is found by means of a system of calibration.

Calibration

As was mentioned, an interferometer system requires calibration and the most accurate means of calibration is the ballistic camera method. With the size of antennas used for space surveillance, however, the far zone of the antenna is many miles high—too high for conventional aircraft.

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[1] J. T. Mengel, "Tracking the earth satellite, and data transmission, by radio," Proc. IRE, vol. 44, pp. 755–760; June, 1956.

[2] H. L. Saxton, NRL Rept. No. 4003, July, 1952. (Confidential.)

[3] J. J. Freeman, "Principles of Noise," John Wiley and Sons, Inc., New York, N. Y., pp. 271–274; 1958.

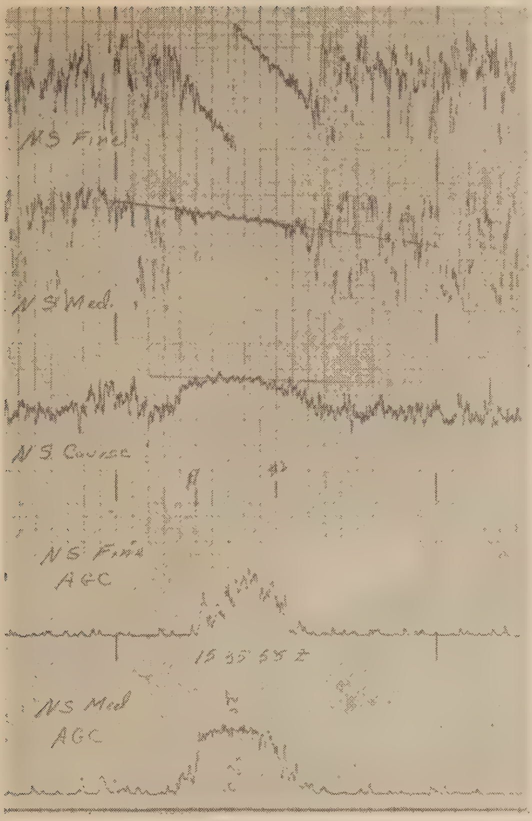

Fig. 2—Reflected signal obtained from 1957 Beta satellite.

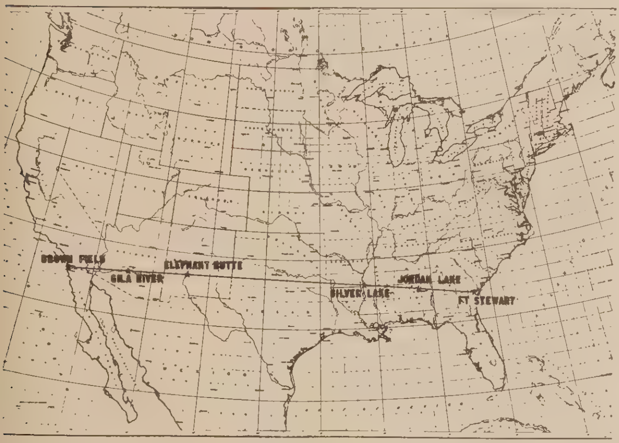

Fig. 3—Location of tracking stations.

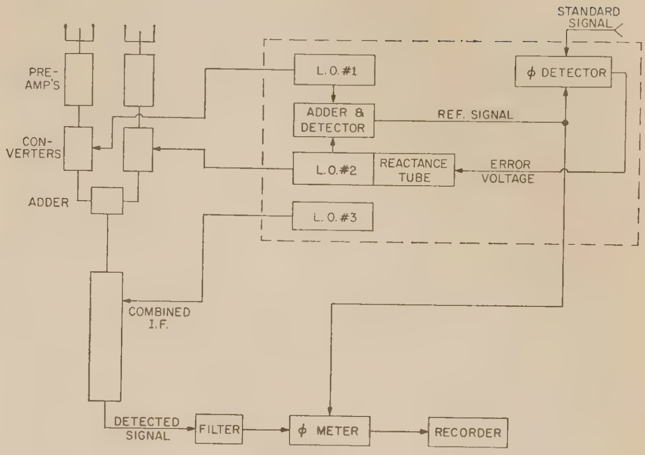

Fig. 4—Block diagram of receiving system.

For calibration a distant source in a known position is required. A device that meets this requirement is the Vanguard I satellite, 1958 Beta, whose position is well known from the orbit computed by NASA. Even though the orbit of this satellite is the best known of any, the data for calibration purposes must still be obtained from post flight rather than predicted data. Once the data is obtained the calibration is made by comparison with the electrical data. Since the orbital data is obtained by calibrating the Minitrack stations against the stars, the Space Surveillance stations are also calibrated against the same standards—though with diminished accuracy.

SIGNALS

Fig. 5 shows the signal obtained from the calibration satellite, 1958 Beta. The inclination of this satellite is nearly the same as the latitude of the Space Surveillance line, so its signals remain in the antenna beamwidth for a considerable time. In general the signal reflected will appear similar to a very small portion of this direct signal, though the reflected signals are much noisier than the direct signals. A reflected signal from another satellite is shown in Fig. 6.

In addition to signals reflected from satellites many extraneous signals are present. They appear as reflections from meteorite trails, from aircraft, and as direct signals from radiating satellites, electrical storms, radio stars, direct feedthrough from transmitter to receiver, and man-made interference. One of the most prevalent interfering signals is due to meteorites. Fig. 7 shows one of the signals obtained during a time of high meteorite activity.

The simplest means of reducing meteorite reflections is illustrated in Fig. 8. Here the polarization of the transmitting antenna is opposite to that used on the receiving antenna. The record also shows a receiving antenna having the same polarization as the transmitter. A count of incidences on the two receiving channels shows that approximately only 5 per cent as many signals appear on the receiving antennas having the opposite polarization to the transmitter as appear on the antenna having the same polarization as the transmitter.

The reason for the reduction in meteorite reflections is understood when it is realized that the meteorite trails in general are formed below the ionosphere and that the most usual excitation of the meteorite trail is the one due to the indivudual electrons oscillating in the polarization of the exciting element. Since the excitation of the transmitting antenna is not subject to Faraday

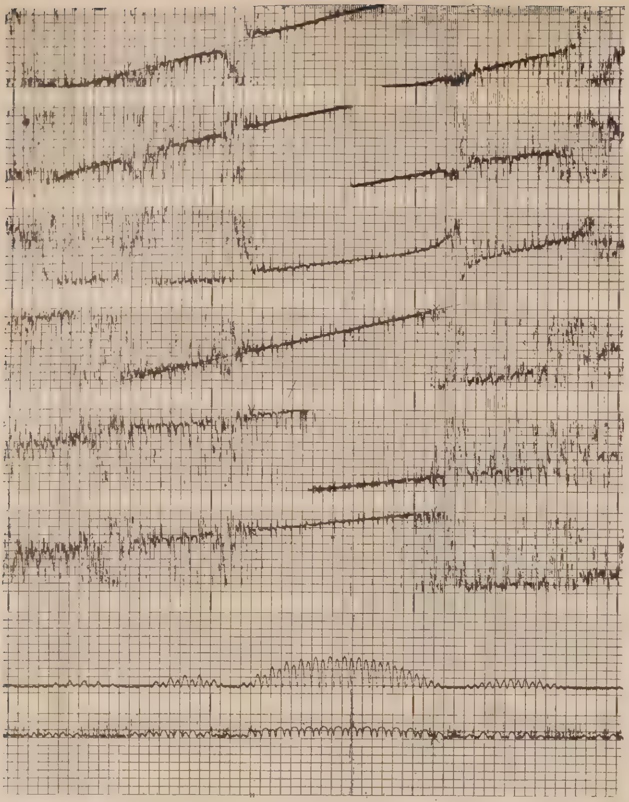

Fig. 5—Direct signal from 1958 Beta 2 (Vanguard I) satellite.

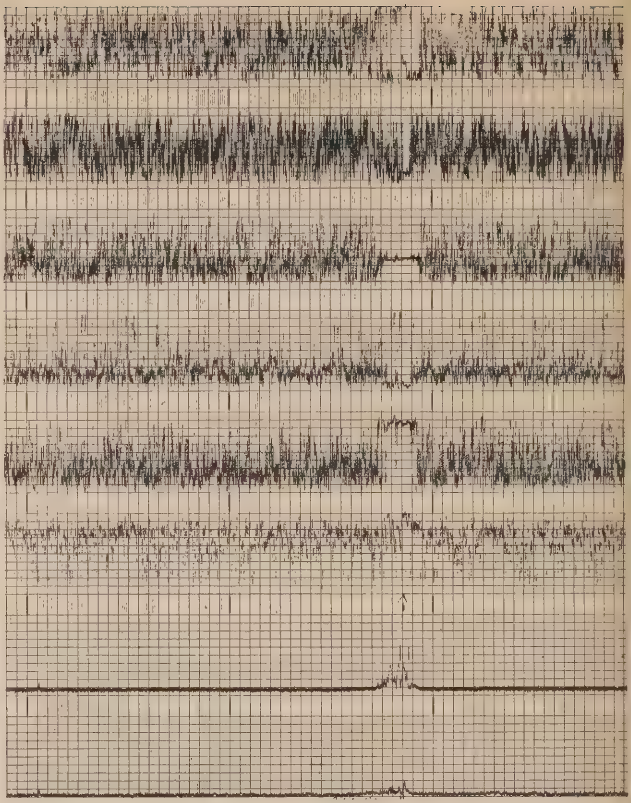

Fig. 7—Reflected signal from meteorite trail.

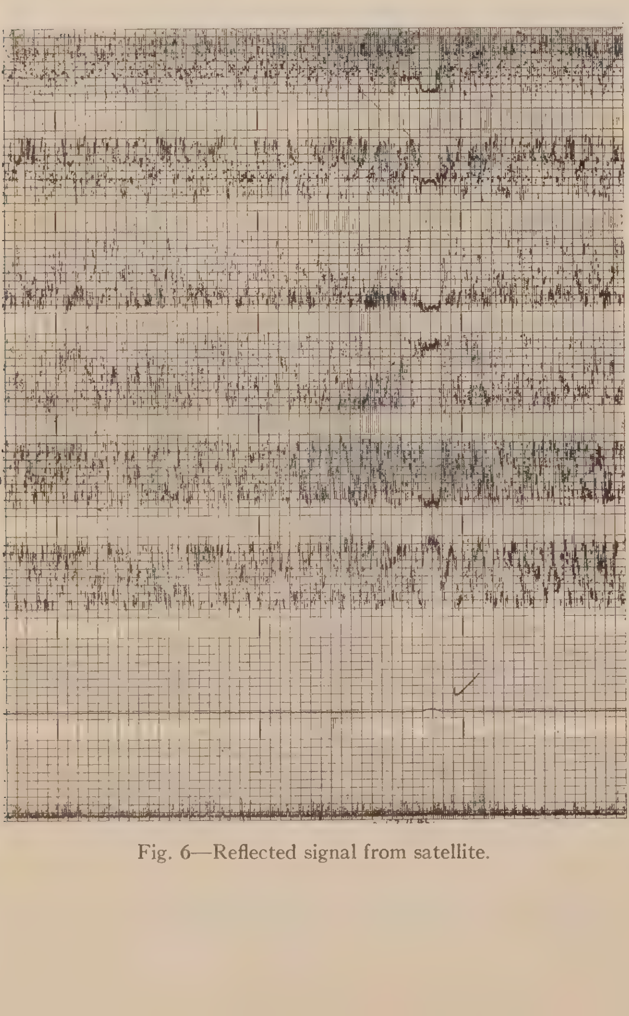

Fig. 6—Reflected signal from satellite.

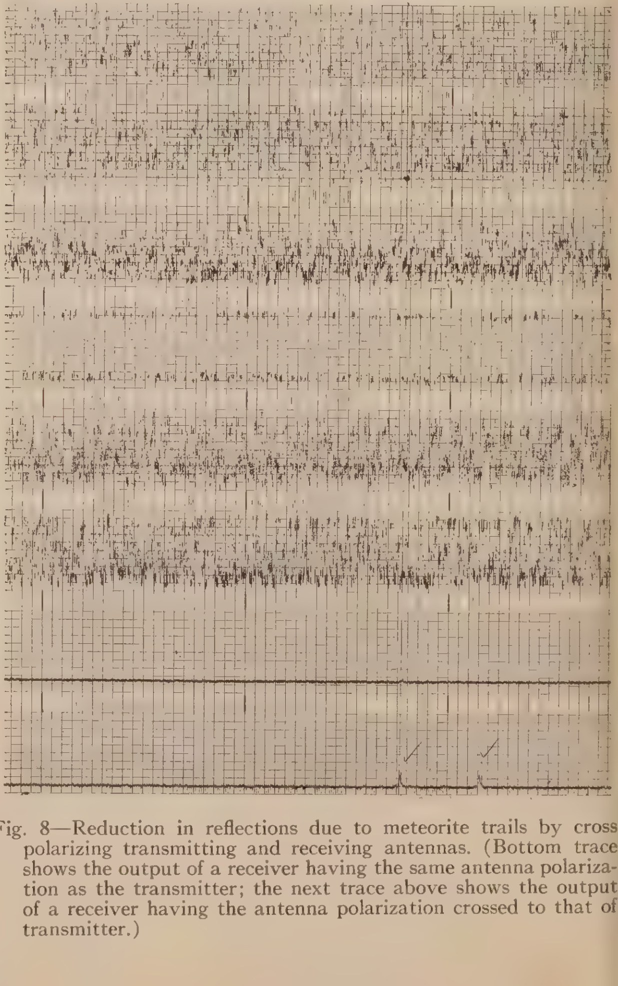

Fig. 8—Reduction in reflections due to meteorite trails by cross polarizing transmitting and receiving antennas. (Bottom trace shows the output of a receiver having the same antenna polarization as the transmitter; the next trace above shows the output of a receiver having the antenna polarization crossed to that of transmitter.)

rotation at the usual height of meteorite trails, the type of reflection described above will be cross-polarized to an antenna having a polarization crossed to the transmitter. Under these conditions the response from meteorites can be expected to be low. Reflections from satellites occur from within or above the ionosphere and the polarization of such signals is subject to Faraday rotation so the polarization of the received signal can be expected to be random.

STATIONS

The stations involve large antenna installations. The Jordan Lake transmitting site is shown in Fig. 9. The Fort Stewart installation is considered the R&D receiving station and hence is larger than the other receiving sites. At each receiving station the information from the phase meters is placed on direct reading recorders and is also placed on phone lines for real time transmission to the Naval Research Laboratory and to the Naval Weapons Laboratory at Dahlgren, Va. The data is sent using standard FM telemetry subcarriers directly on a standard telephone line.

SPACE SURVEILLANCE OPERATIONS CENTER

During the experimental phase of system operation, the Space Surveillance Control Center is located at NRL. It is normally operated on an 8-hour day and 5-day week. An experimental operations center is also located there both for the development of improved operational techniques and for serving as a backup for the Space Surveillance Operations Center at Dahlgren, Va., which is in operation around-the-clock seven days a week. The analog data representing phase and signal-level information of interest are read manually immediately after they are recorded at Dahlgren. The observations are used for improving the predictions of known satellites and determining the orbits of unknown satellites crossing the Space Surveillance line.

The Space Surveillance Operations Center has been established at the Naval Weapons Laboratory (Dahlgren, Va.) so that it could take advantage of the NORC (Naval Ordnance Research Computer) and of the NWL staff. The NORC computer is especially well suited for orbit computations since it has both a high precision (13 significant decimal digits plus sign and exponent) and a high speed (15,000 operations per second). A picture of the NORC is shown in Fig. 10 and a table of its operating characteristics is as follows:

Number system:	Decimal (Automatic floating point).
Word size:	16 digits and check digit.
Instructions:	3-address.
Storage capacity:	2000 words (electrostatic). 20,000 words (magnetic core) being added.
Storage access time:	8 μsec.
Multiplication time:	31 μsec.
Addition time:	15 μsec.
Magnetic tape units:	8 operating at 70,000 characters per second.
Printers:	2 mechanical operating at 300 characters per second. 1 optical printer operating at 15,000 characters per second.

Fig. 9—The Jordan Lake transmitting site.

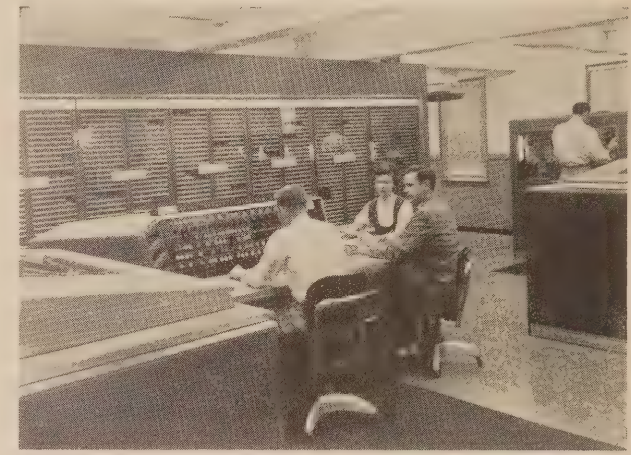

Fig. 10—The Naval Ordnance Research Computer (NORC).

ORBIT COMPUTATIONS

The mathematical formulation of the orbit-computation programs has been the responsibility of Dr. P. Herget (Director of the Cincinnati Observatory) under contract to NRL and of Dr. G. M. Clemence and Dr. R. L. Duncombe, both of the U. S. Naval Observatory. The analysis, programming, and some of the mathematical formulation are being done by NWL.

The orbit computations required for satellites are divided into two parts: a) determination of the orbital elements from the observations, and b) prediction of future satellite positions from these elements (compilation of an ephemeris). For initial orbit determination and prediction, Cowell's method of numerical integration[4] is used; for large numbers of observations, the method of general oblateness perturbations[5] is employed. Six elements are needed to describe an elliptical orbit at some given time T_0 (called the epoch). These elements are derived from the observations when there is sufficient information available to be equivalent to a position vector and a velocity vector at a given time.

The orbital elements are refined automatically on the NORC by successive application of a differential correction procedure until the residuals between all the observations and the positions computed from the elements have become small. The best available set of elements is used to compute a position vector in geocentric inertial space for the satellite for every minute of time in the future (for days or weeks, depending on the type or orbit) for predictions. Both in orbit determination and prediction, the position of the satellite as computed from the elements is corrected for perturbations due to the earth's oblateness and atmospheric drag. Depending on the requirements of the user, predictions as needed are computed in the form of a world map (longitude and latitude of the subsatellite point on the earth and the height of the satellite above the earth), or of local station predictions (range, bearing, and elevation information at frequent time intervals for optical instruments or narrow-beam radars to view the satellite), or of beam-crossing predictions (time, height above the earth, and zenith angle) for Space Surveillance stations.

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[4] P. Herget, "The Computation of Orbits," 1958. (Published by the author.)

[5] P. Herget and P. Munsen, "A modified Hansen lunar theory for artificial satellites," *Astronomical J.*, vol. 63, pp. 430–433; November, 1958.

The six elements needed to describe an elliptical orbit at time T_0 (epoch) may be given as follows:

Semimajor axis (a)
Eccentricity (e)
Inclination (i)
Right ascension of ascending node (θ_0)
Argument of perigee (ω_0)
Mean anomaly at epoch (M_0).

The epoch is given as the year, month, day, hour, minute, and second in universal time. The semimajor axis of the ellipse is measured in earth's equatorial radii (equatorial radius is 3963.34 statute miles based on the international ellipsoid for the shape of the earth[6]). The eccentricity is a ratio which is always less than unity for an ellipse and is equal to zero for a circle. The inclination (see Fig. 11) is the angle measured in degrees from the equatorial plane of the earth to the orbital plane at the ascending node (that is, where the satellite crosses the equator in a northward direction). The right ascension of the ascending node is measured in degrees eastward along the earth's equator from the vernal equinox to the ascending node. The vernal equinox establishes the x-axis for the geocentric inertial coordinate system, the z-axis passing through the earth's North pole, and the y-axis lying in the equatorial plane to form a right-handed coordinate system. The argument of perigee (point of closest approach to the earth) is the angle in degrees measured in the orbital plane from the ascending node to the perigee. The mean anomaly at epoch is given in degrees and represents the position of the satellite in the orbit with respect to the perigee.

If there were no disturbing forces exerted on the satellite, its orbit would not change with time and predictions of future satellite positions would be made simply on the basis of an ellipse fixed in inertial space. For most artificial earth satellites, there are two major disturbing forces which must be taken into account: one resulting from the shape of the earth (the equatorial bulge), and one resulting from the presence of the atmosphere. Because of the distribution of the mass of the earth, there is motion of the perigee in the orbital plane and motion of the node in the equatorial plane. Because of the energy removed from the orbit by atmospheric drag on the satellite, the orbit collapses with time, the apogee (farthest point from the earth) shrinking many times faster than the perigee. These perturbations are taken into account both in orbit determination and prediction.

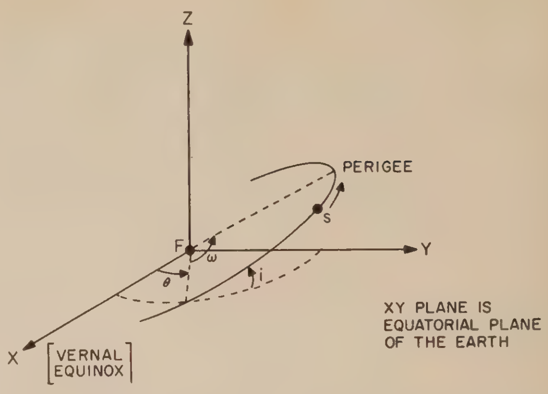

Fig. 11—Coordinate reference system.

An example of a complete set of elements and related information is given for the satellite 1958 Beta 2 (Vanguard I) as released from the Vanguard Computing Center as follows:

Epoch	October 22, 1959	122700 UT
Anomalistic period	134.04899	Minutes
Period decay	−0.0001	Minutes per day
Inclination	34.249	Degrees
R.A. of ascending node	191.613	Degrees
Motion of node	−3.023	Degrees per day
Argument of perigee	182.671	Degrees
Motion of perigee	4.415	Degrees per day
Latitude of perigee	−1.503	Degrees
Mean anomaly at epoch	160.459	Degrees
Eccentricity	0.18963	
Semimajor axis	1.36030	Earth radii
Perigee height	405.6	Statute miles
Apogee height	2,450.3	Statute miles
Velocity at perigee	18,371	Miles per hour
Velocity at apogee	12,514	Miles per hour

The anomalistic period is the time for the satellite to make a complete revolution from perigee to perigee. Depending on the orbital elements, the motions of node and perigee are only a few degrees a day at most. For a polar orbit ($i=90°$), there is no motion of the node; and for an orbit having an inclination of $63\frac{1}{2}°$, there is no motion of the perigee. The perigee and apogee heights are measured from the surface of the earth, which is taken to correspond to the equatorial radius in this case.

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[6] "The American Ephemeris and Nautical Almanac for the Year 1959," U. S. Naval Observatory, Washington, D. C.; 1957.

A catalog of all satellites is maintained by the NORC computer and can be displayed as subsatellite positions projected on a world map. Fig. 12 illustrates the appearance of the display, called SPASCORE, for which the film is normally projected at one frame per minute in "real time" but may be run forward or backward at 20 frames per second. The map overlay on the projection screen is a modified cylindrical projection of the earth. The subsatellite positions are calculated by the NORC and automatically recorded on 35-mm film from a Charactron cathode-ray-tube output device, which is also used as an optical printer for alphanumeric data output. This equipment provides great versatility in displaying the computer output; it can be operated on-line with the computer to project the output in real-time with a delay of as little as eight seconds or to record the output on film at 40 frames per second for later development and projection.

The most important output of the Space Surveillance System is information on nonradiating satellites. Orbital elements can be computed and predictions of future satellite positions can be given to those authorized to receive such information. The System also has been used to augment the observations of radiating satellites.

Discussion

The radal (radio detection and location) system described differs from a pulse radar in principle and in detail differs greatly. Pulse radar[7] uses a single installation from which energy is transmitted and received. The location of reflecting objects is inferred from the angle of arrival and from the time delay between transmission and reception. Previous to and during World War II the angle of reception was derived from the antenna direction. The monopulse radar,[8] also developed at this Laboratory, derives its angular information from several simultaneous observations of the angle of reception of the incident wave. Pulse radars were developed for detecting and tracking ships and aircraft, objects which have great maneuverability but low speeds.

The radal system is designed to detect and locate objects having great speed but very limited maneuverability. For such objects a great range capability but a modest number of sightings serves to determine the path of the object for days to come.

To satisfy the requirement of detection at great ranges the system has been designed to maximize range capability. Since a larger average power can be generated economically at CW than with pulses, a CW system is indicated. To use antennas having large capture areas without unusably small beamwidths, a low frequency is used. The antenna beamwidths are designed to detect over a large angle in one direction and a very narrow angle in the other. This technique permits detection of objects passing through an area of large dimensions but small volume.

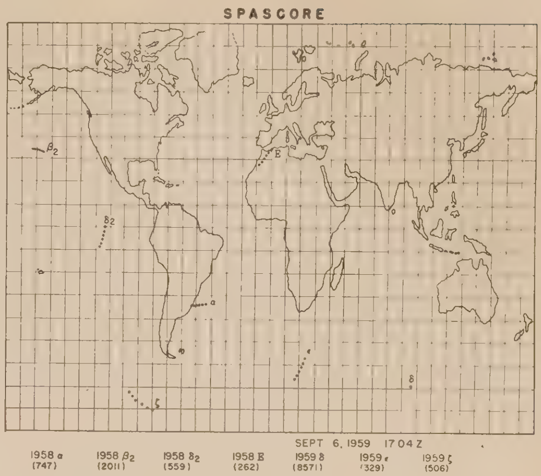

Fig. 12—NORC output display (SPASCORE).

An integral part of the Space Surveillance System is a high-precision, high-speed digital computer to process the observations with a minimum time delay. Thus a catalog of all orbiting objects within range of the system is maintained to produce predictions of their future positions for the use of authorized customers.

The present system has demonstrated itself to be effective and reliable. Improvements are planned and will be installed as time and funds allow. An additional transmitter is expected to be located in the central portion of the line in the near future. The present system of analog data transmission and manual data reading is expected to be replaced by a digital transmission system to permit fully automatic data handling by the computer.

Acknowledgment

The authors wish to acknowledge their indebtedness to Dr. C. E. Cleeton, Superintendent of the Applications Research Division, and Captain W. E. Berg, Senior Program Officer for Military Applications of Satellites, U. S. Naval Research Laboratory, Washington, D. C., for their continuing helpful guidance on the Space Surveillance project, which has engaged the talents and interest of a large part of the Division. Above all, they wish to acknowledge the tireless efforts of their colleagues, to whom they attribute the success of the project.

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[7] A. H. Taylor, "Radio Reminiscences: a Half Century," Naval Research Lab., Washington, D. C., pp. 294–308; 1948.

[8] R. M. Page, "Monopulse radar," 1955 IRE Convention Record, pt. 8; pp. 132–134.

Ionospheric Scintillations of Satellite Signals*

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Summary—The scintillation of satellite-emitted radio signals has been observed using two different techniques, namely, Doppler-shift frequency measurements and radio direction finding. In this shortened version of our complete paper, there are given the results obtained using Doppler-shift measurements only. Variations from a smooth Doppler-shift curve obtained during individual orbits give a measure of the frequency scintillation occurring and thus of the roughness of the ionospheric path between the satellite and the observer. As expected, these variations are a function of frequency, and they become less as the frequency is increased.

The Doppler shift that is observed is primarily a function of the radial velocity of the satellite with respect to the observer and the emitted frequency. However, for frequencies in the region between 20 and a few hundred mc, the effects of the wave velocity of propagation through the ionosphere as a function of the refractive index are noticeable. Therefore, the observed Doppler shift is further affected by changes in refractive index or ionization along the path between the satellite's position and that of the observer. Also the Doppler shift is affected by the intensity of ionization at the satellite. The degree to which the observed variations are attributable either to changes in ionization at the satellite when the satellite is passing through the ionosphere or to changes in the integral of electron density along the path, is a suitable subject for further study.

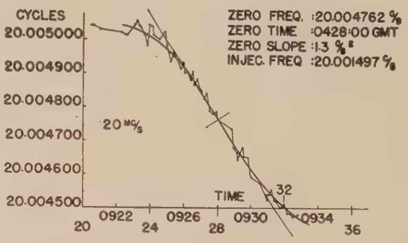

Fig. 1—Satellite δ 1958, orbit #2294, October 29, 1958.

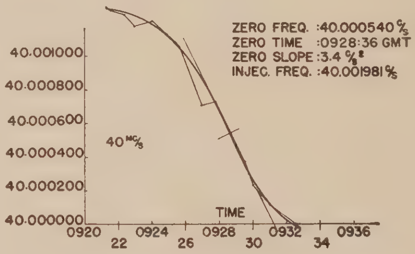

Fig. 2—Satellite δ 1958, orbit #2294, October 29, 1958.

These frequency measurements were taken with an instrumental accuracy of ±7 cycles in frequency measurement and at 1-second time intervals based on simultaneous reception of WWV standard time transmissions. Fig. 1 shows the deviations of the observed Doppler-shift recordings of Sputnik III from a smooth curve drawn through the observed points. It is seen that substantial variations occur even during the point of nearest approach of the satellite. Fig. 2 shows the variations observed with the first harmonic on the same orbit, namely for 40 mc. It is seen that even at this frequency substantial scintillations occur as deviations from a smooth curve. Now, going to 108 mc we see a fairly smooth curve described by observations of Explorer I shown in Fig. 3. The center part is quite smooth but, as expected from a longer ionospheric path at the outer ends of the curve, these ends show some deviations from a smooth curve. This orbit has an apogee of 2500 km and a perigee of 360 km. Thus, for a good part of the time it lies within the ionosphere, and the ionospheric path from the observer to the satellite is somewhat less than the total thickness of the ionosphere in the direction of the satellite.

Such is not the case for the orbit of Vanguard I, which at all times is well above the maximum of the normal *F* region. Its orbit has an apogee of 3960 km and a perigee of 660 km. Fig. 4 shows frequency deviations of the order of 20 to 25 cycles observed during a particular orbit of Vanguard I. This orbit occurred during a time when the ionospheric quality figure was 7 (good). Subsequently, on the next day, there occurred the largest short-period deviation, which we have observed on the 108-mc signals (Fig. 5). This anomoly also was taken from an orbit of Vanguard I. It appears to be of greater magnitude than what might be expected from variations in the integrated electron density of the ionosphere. The quality index was "good" again. Since the orbit of this satellite is well above the normal *F* region, and at the time of this observation the satellite was at an altitude of approximately 3900 km, that is, close to its apogee, a possibility exists that the occurrence may have been caused by the satellite encountering a cloud of charged particles above the ionosphere. However, one must also consider the possibility of an ionized cloud coming between the satellite's position and the observer for the three-minute time duration of the anomoly by some disturbance in the *F* region of the ionosphere.

From this and the previous illustrations, it is clear that ionospheric frequency scintillations of substantial magnitudes do occur with satellite signals. This observation coincides with the so-called "color" scintillations

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* Original manuscript received by the IRE, December 2, 1959; revised manuscript received, March 2, 1960. This is a shortened version of a paper which will appear in full in the *Proceedings of the Tenth International Astronautical Congress*, published by the Springer-Verlag, Vienna, Austria.

† U. S. Army Signal Research and Development Lab., Fort Monmouth, N. J.

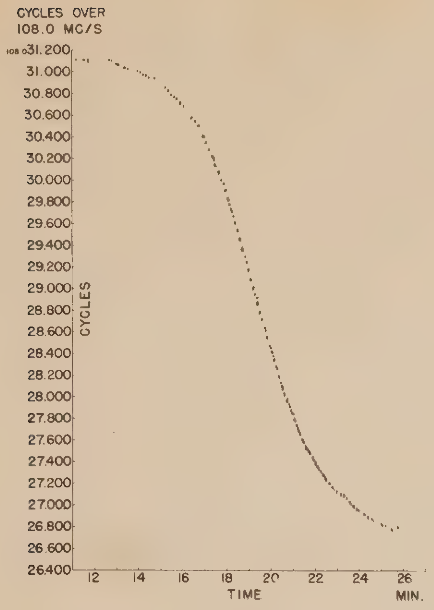

Fig. 3—Satellite 1958 α, orbit #97, February 8, 1958. Time reference 1811:00 EST.

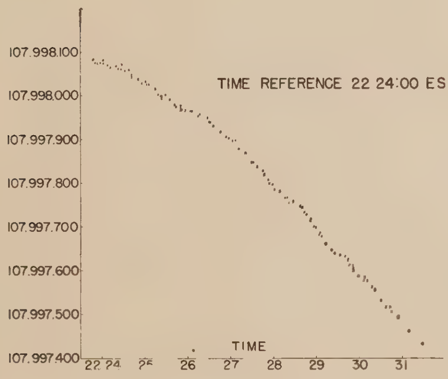

Fig. 4—Satellite β 1958, orbit #128, March 28, 1958.

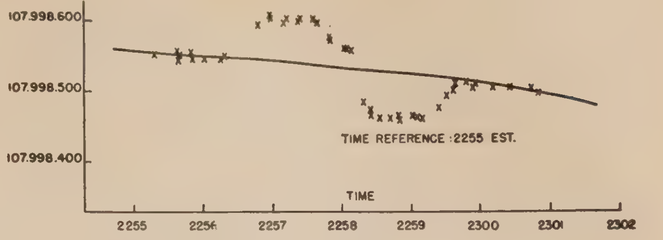

Fig. 5—Satellite β 1958, orbit #138, March 29, 1958.

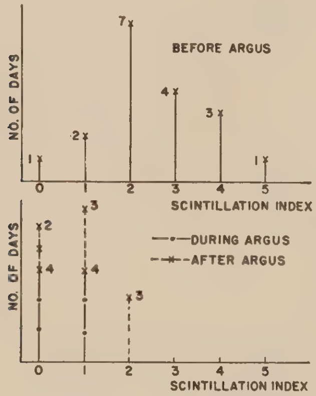

Fig. 6—Distribution of scintillation quality index.

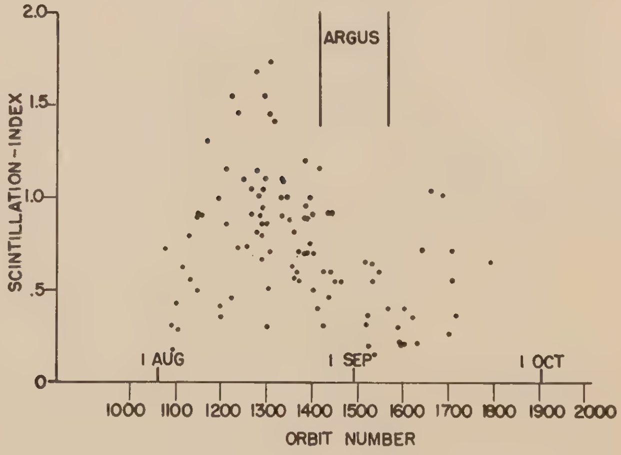

Fig. 7—Delta '58 Sputnik III.

of the radio star signals which have been cited by Little.[1] With the recent public announcement of the Argus high-altitude nuclear detonations and the Christofilos effect, our Doppler-shift recordings were studied to see whether any systematic effect was discernible. As a preliminary measurement, the records of eighty-nine orbits were examined visually and ranked on a qualitative grading basis from 0 to 5 with the number zero denoting no scintillations and the number five, maximum scintillations. We call this a scintillation quality index. These observations were all on Sputnik III orbits and taken at 20 mc, which is our most sensitive frequency for that purpose. Fig. 6 shows histograms of these distributions taken before, during and after the three Argus high-altitude detonations. It is clearly seen that systematic changes occurred which initially showed a strong reduction in scintillation of the Doppler-shift signals, and even several days later indicated a much lower index than for the period before the detonations. Meanwhile, quantitative measurements were initiated using the measured areas generated by the difference between a smoothed curve through the data and the curve generated by the data points. For each orbit this area was measured in arbitrary units and the resultant number was divided by the time (in minutes) of the observation. The results of this procedure are shown in Fig. 7, where data to the left of the first vertical line cover the period of 18 days prior to the first detonation, and to the right, the period of 16 days afterwards. It is clear that in this latter period the scintillations of these Sputnik III signals were systematically less than prior to the event.

[1] G. Little, "The Jodrell Bank program on meteors, aurora, and ionosphere," *J. Geophys. Res.*, vol. 59, pp. 152–155; March, 1954.

The Satellite Ionization Phenomenon*

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W. R. CRONE†, MEMBER, IRE

Summary—**A number of observations are presented which show a close correlation between CW-reflected HF signals and passes of artificial earth satellites. The periodic (nonrandom) occurrence of the signal bursts and the symmetry of some burst sequences are indicative of satellite-related phenomena. The occurrence of a variety of satellite-related Doppler effects are described and several satellite ionization mechanisms are also discussed. The possible relation of the satellite phenomenon to prior solar activity is mentioned.**

INTRODUCTION

IN an earlier communication,[1] it was suggested that some anomalies in the signals from Sputnik I, noted at The Ohio State University Radio Observatory in October, 1957, might be caused by satellite-induced ionization. Subsequent experiments using CW reflection provided evidence that artificial earth satellites could, on occasion, be detected due to such ionization.[2,3] The CW-reflection technique was the same as employed earlier by Wylie and Castillo[4] for observing meteors, a standard short-wave receiver being used to monitor the transmissions of WWV, near Washington, D. C., on 20 mc.

During the day, ionospheric ionization is usually sufficient to reflect a strong signal from Washington to Columbus on this frequency. However, at night and in particular between midnight and 6 A.M. local time, the signals from WWV become extremely weak or inaudible except for brief signal bursts which appear to be associated with temporary localized increases in ionization in the ionosphere. Although many of the signal bursts were probably due to meteors, the marked periodicity of many of the longer and stronger bursts suggested that they were satellite related, many occurring close to the time of near approach of Sputniks I or II. Bursts caused by meteors would be expected to occur in time in a random manner; hence, it appeared highly probable that mechanisms other than meteor ionization were involved.

Many CW-reflection observations have been made subsequently which show effects related to other satellites. As an example, signal bursts observed on some of the first passes of Sputnik III are presented in the next section. The following section describes CW-reflection signal bursts observed during the next few weeks which can be interpreted as due to the systematic separation of the Sputnik III objects because of their differing drag characteristics. Later sections describe burst periodicities of very short period (order of 1 minute), symmetrical burst sequences, Doppler and other phenomena which appear to be satellite related, and a number of mechanisms which may account for the satellite-induced ionization.

OBSERVATIONS OF SPUTNIK III ON ITS FIRST PASSES

An interesting series of observations was made soon after Sputnik III was launched on May 15, 1958. At 7:19 A.M. EST, a WWV signal burst was recorded as Sputnik III crossed western Europe on the completion of its second trip around the earth. This burst is shown in the top record in Fig. 1, which is a photograph of the original Esterline-Angus tape made at the time. Time increases from right to left.

One hour and 47 minutes later, or at 9:06 A.M., a group of weak WWV bursts was recorded (second record from top in Fig. 1). At this time, Sputnik III was completing its third trip and was over the middle of the Atlantic Ocean. Another hour and 47 minutes later, or at 10:53 A.M., a series of strong WWV bursts was recorded as Sputnik III was completing its fourth trip and passing northeastward off the east coast of the United States (third record from top in Fig. 1). One hour and 47 minutes later, a fourth series of strong WWV bursts plus background enhancement were recorded as Sputnik III completed its fifth trip, over the central part of the United States (fourth record from top in Fig. 1). On the following day (May 16, 1958), during the Sputnik III pass over the eastern United States at 11:35 A.M., a series of strong WWV bursts was recorded (bottom record in Fig. 1).

The bars under the lower three records in Fig. 1 indicate the approximate times of near approach of the satellite as determined by observations of the Sputnik III transmissions on 20.005 mc. All deflections of the pen showing on the records for these passes were monitored by an operator and identified as being due to WWV (20.000 mc). Parts of the records are missing because at these times the receiver beat frequency oscillator (BFO) was turned on.

The WWV burst groups corresponding closely to the passes of Sputnik III at 10:53 A.M. and 12:40 P.M. on

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* Original manuscript received by the IRE, December 23, 1959. Supported in part by the Army Rocket and Guided Missile Agency, U. S. Army Ordnance Missile Command, under contract with The Ohio State University Research Foundation, and by The Ohio State University Fund for Basic Research.

† Radio Observatory, Dept. of Elec. Engrg., Ohio State University, Columbus, Ohio.

[1] J. D. Kraus and J. S. Albus, "A note on some signal characteristics of Sputnik I," PROC. IRE, vol. 46, pp. 610–611; March, 1958.

[2] J. D. Kraus, "Detection of Sputnik I and II by CW reflection," PROC. IRE, vol. 46, pp. 611–612; March, 1958.

[3] J. D. Kraus, R. C. Higgy, and J. S. Albus, "Observations of the U. S. Satellites Explorers I and III by CW reflection," PROC. IRE, vol. 46, p. 1534; August, 1958.

[4] L. R. Wylie and H. T. Castillo, "Clustering of meteors as detected by the use of radio technique," *Ohio J. Science*, vol. 56, pp. 339–347; November, 1956.

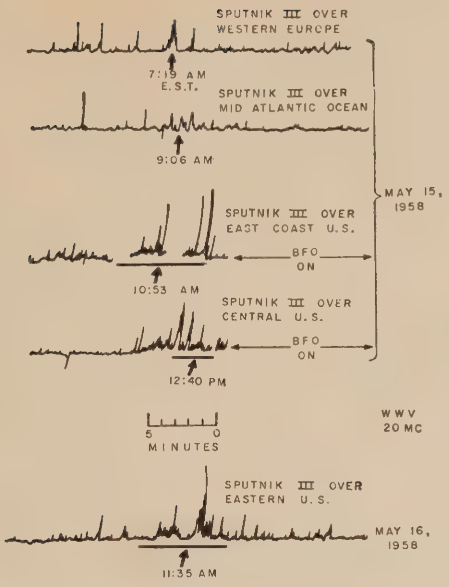

Fig. 1—Records of WWV 20-mc signals obtained during the first passes of Sputnik III on May 15 and 16, 1958. The times of near approach of the satellite are indicated by the heavy arrows.

May 15 and at 11:35 A.M. on May 16 are a striking phenomenon. It is highly improbable that these burst groups were caused by anything other than Sputnik III or effects associated with it. At that time, the instrumented satellite of Sputnik III, its large rocket carrier and several associated pieces of hardware were all close together in orbit. These components had only been in orbit for a short while and might conceivably have been degassing heavily, since they were operating in a nearly perfect vacuum and only shortly before had been at full atmospheric pressure.

The bursts at 7:19 and 9:06 A.M. on May 15 are not as strong, and although they occurred at the time of nearest approach of the satellite, their relation to the satellite is less certain.

Ordinarily, WWV puts a very strong signal into Columbus on 20 mc after 6 or 8 A.M. (EST). However, on the mornings of both May 15 and 16, the WWV level was very weak and close to the level ordinarily observed earlier in the morning between 12 and 6 A.M.

Observations of Sputnik III Objects Between May 26 and June 7, 1958

During the period a few weeks after Sputnik III was put into orbit, many records of the WWV 20-mc signals recorded at The Ohio State University Radio Observatory showed a large burst occurring consistently before the near approach of the Sputnik III instrumented satellite (1958 Delta 2). Of particular interest was the fact that the burst did not occur a constant number of minutes before the near approach of the satellite, but rather the time increased by a few minutes each day. A number of records of WWV 20-mc signals between May 26 and June 7, 1958 illustrating this effect are presented in Fig. 2. The characteristic 4-minute off periods of WWV from the 45th to the 49th minute of each hour may be noted on a number of the records. All records are so arranged that the time of nearest approach of the instrumented satellite is above the 0 minute point (scale at bottom). These times were determined by observations of the satellite's 20.005-mc transmissions by means of other receivers.

The receiver selectivity was sufficiently sharp that the satellite 20.005-mc transmissions do not show on the records in Fig. 2. At the right, a large WWV burst may be noted which occurs progressively earlier (further to the right) each day with respect to the time of nearest approach of the instrumented satellite. On May 26, the burst was about 30 minutes before the instrumented satellite and by June 7, it was nearly 70 minutes before. A line through these bursts extrapolated back intersects the zero line (for the instrumented satellite) at about May 15, which was the launching date, thus suggesting that this object was coincident with the instrumented satellite on that date. The line giving the approximate passage times for the rocket carrier (1958 Delta 1) determined from other data is indicated at the upper right of Fig. 2. Hence, if the moving series of bursts was due to an orbiting object, it could not have been either the instrumented satellite or the rocket carrier. Perhaps this object was one of the other pieces of hardware (nose cone or side shields) separated from these satellites at the time when they were put into orbit. Its period was obviously longer than that of the rocket but less than that of the instrumented satellite.

It is to be noted in Fig. 2 that large WWV bursts occurred on nearly all of the records at or somewhat before the time of nearest approach of the instrumented satellite (0 line). However, these bursts are not as large as for the earlier object. A further point of interest is that relatively few bursts were detected which appeared to be associated with the large rocket carrier. Hence, if these observations are significant, it may be concluded that the size of an artificial satellite is not necessarily the most important factor in producing detectable ionization.

The increasing separation between the bursts in Fig. 2 appears to be due to the systematic separation of the Sputnik III objects because of their differing drag characteristics. These observations are reminiscent of the burst groups detected during the terminal phase of Sputnik I due presumably to the gradual separation of a number of fragments of the satellite.[5]

Burst Groups of 1-Minute Period

As mentioned earlier, a marked periodicity in the WWV signal bursts may be taken as evidence of ionization induced by mechanisms other than meteors. Thus, burst periodicities corresponding to the orbital period

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[5] J. D. Kraus and E. E. Dreese, "Sputnik I's last days in orbit," Proc. IRE, vol. 46, pp. 1580–1587; September, 1958.

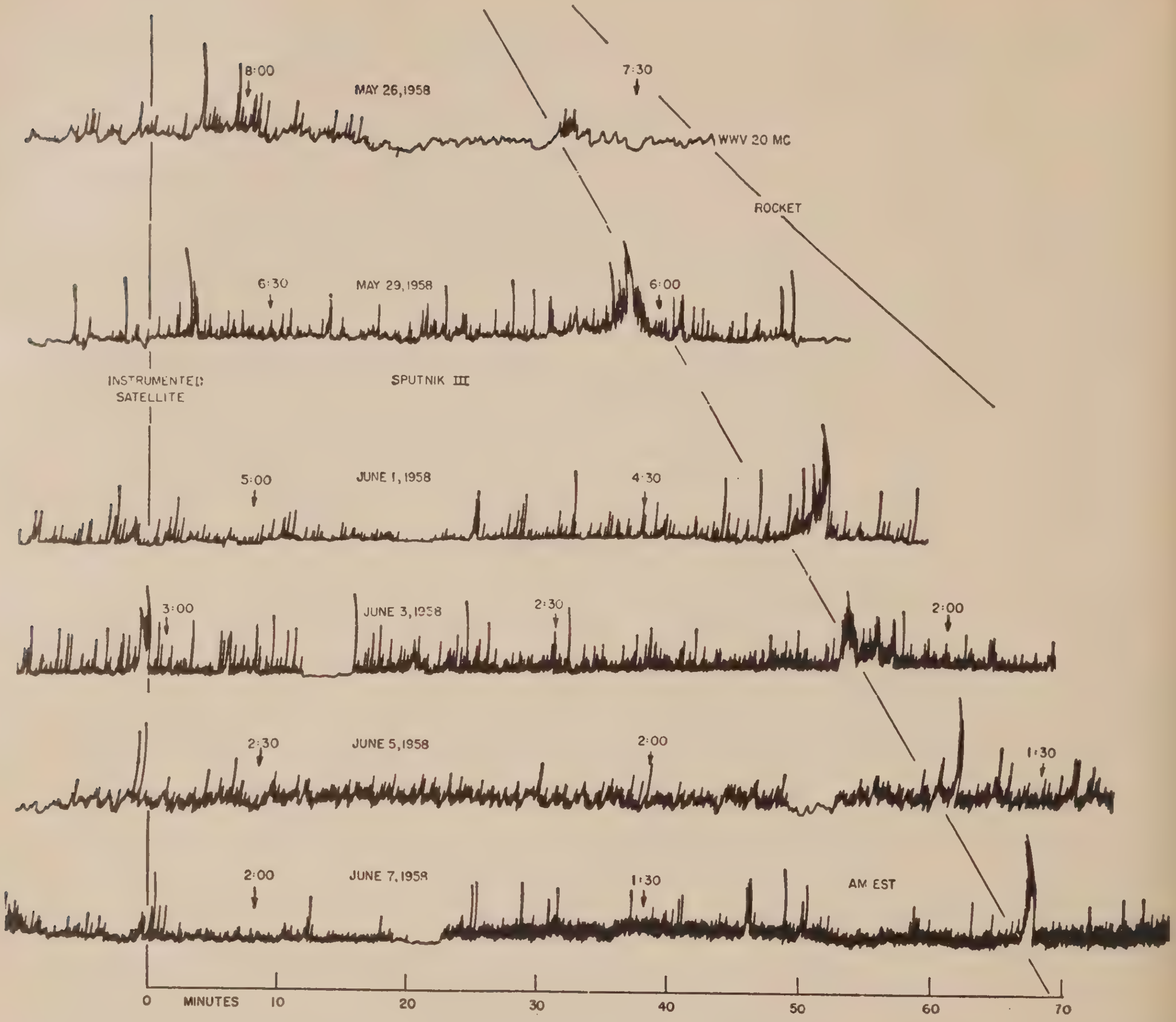

Fig. 2—Records of WWV 20-mc signals with relation to passes of Sputnik III. A large WWV burst is seen to move further ahead of the instrumented satellite on succeeding days. A line drawn through this series of bursts and extrapolated back intersects the vertical line for the instrumented satellite, and also a line for the rocket carrier, on May 15, 1958, the launching date, suggesting that the series of bursts may have been due to one of the other Sputnik III objects (such as the nose cone or side shields).

of artificial earth satellites, as described in the previous sections, suggest ionization induced by satellites. On many occasions, a much shorter period, of the order of 1 minute, was observed for groups of signal bursts occurring at the time of near approach of a satellite. In a typical example, a well-defined group of 10 to 15 bursts, each of 5- to 10-seconds duration, was observed to occur close to the time of near approach of Sputnik II. The spacing between bursts was remarkably constant, averaging 59 seconds with a mean deviation of 5 seconds. The amplitude of the bursts was in nearly all cases greater than that of bursts observed before or after the group. Furthermore, the largest bursts occurred near the center of the group. Between the bursts, the signal level was substantially zero so that the group had the appearance of a series of regularly-spaced spikes decreasing in amplitude from the middle to both the beginning and end of the group. It appears probable that these burst groups were related to Sputnik II. The fact that the tumbling period of the satellite was about 1 minute also favors this interpretation. However, the periodicity could have been related to the charge-discharge time of the satellite (see the section on Ionization Mechanisms) or to the spacing of relatively dense ionized bands or zones in the Van Allen belts or other regions through which the satellite was passing.

Symmetrical Burst Sequences

Groups of signal bursts differing from those described in the previous section have also been observed at The Ohio State University Radio Observatory. These burst groups are characterized by an even more symmetrical series of bursts with many of the bursts lasting about 1 minute. An example of such a symmetrical burst sequence is shown by the record of Fig. 3. The center trace is a record of the WWV 20-mc signal strength as a function of time for the morning of October 8, 1958. An Esterline-Augus recorder was used with time increasing from right to left.

A remarkably symmetrical series of bursts is evident with the center point at 4:22.8 A.M. EST. At this moment, the transmitterless Sputnik III rocket carrier was close to the north magnetic pole. It was also at its point of nearest approach to Columbus and was passing through the center of the beam of the receiving antenna. The geometry of the pass as viewed from the vicinity of the north pole is indicated by the sketch at the top of Fig. 3. The path of the Sputnik III rocket from west to east (across Hudson Bay) is shown by the track running from right to left with Columbus 1750 miles to the south (or above in the sketch). The curve marked 60° is the 60th parallel of latitude. Columbus is at 40° north latitude.

The scale along the path indicates the position of the satellite as a function of time. The scale of this sketch was chosen to correspond to the time scale of the chart record of the WWV bursts in the center trace. Thus, at about 4:15, when the satellite was approaching from the west, there was a large short-duration WWV burst. As the satellite approached closer, a series of more sustained bursts occurred which reached a maximum amplitude at about 4:23 when the satellite was in the center of the receiving antenna beam and close to its point of nearest approach. As the satellite traveled further east (to the left), the bursts decreased in amplitude until at about 4:31 when there was another large short-duration burst. Lines with arrows extending downward from the satellite path indicate the events occurring at the corresponding times on the WWV record. The record would suggest that the observed signals were in this case due to reflections of WWV signals from ionization induced by the Sputnik III rocket.

The receiving antenna used during these observations was a three-element horizontally-polarized beam antenna directed about 10° east of north. This direction was chosen as giving a minimum of response to WWV under ordinary conditions. The antenna power pattern is indicated in the sketch at the top of Fig. 3. The recorded response should be a function not only of this pattern, but also of the distance of the satellite path from Columbus.

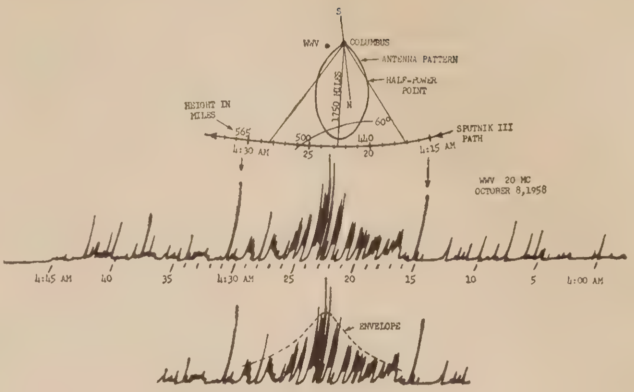

Fig. 3—Record of the WWV 20-mc signal obtained on October 8, 1958, during the passage of the Sputnik III rocket through the antenna beam (center trace). The sketch at the top of the figure shows the pass geometry as viewed from the vicinity of the north pole. The record of the WWV signal is reproduced again at the bottom of the figure with an envelope (dashed line) drawn over the burst pattern.

In order, however, to obtain a calculated response curve which corresponds to the envelope drawn over the bursts at the bottom of Fig. 3, as shown by the dashed line, an additional factor is required which suggests a considerable aspect sensitivity to the response. That is, the strength of the signal bursts appears to fall off rapidly as the angle between the radius vector and satellite path becomes less than 90°, which is the condition for a specular reflection from an ionized column along the satellite path. The brief spikes of WWV signal observed at about 4:23 may also be momentary enhancements which occurred when the reflection was specular, and, if this is the case, the aspect sensitivity is even greater than suggested above since the envelope in Fig. 3 was not drawn over these spikes.

Magnetic sound tape recordings made of the 20-mc signals at the time of the pass reveal the characteristic WWV signal in many of the bursts. In the more sustained bursts, a rapid flutter fading is evident, and in some of the strongest bursts near 4:23, the fading is so severe as to mask the WWV signal characteristics in a very hashy type of random noise. High-speed paper tape recordings of the signals from the magnetic sound tape show a very definite amplitude modulation (about 50 per cent) of the reflected WWV signal with a period of about 9 seconds. This period is the same as the tumbling period of the satellite which suggests that the ionization produced by the satellite is a function of the physical cross section of the satellite normal to its path.

It may be significant that the Sputnik III rocket passed north of the center of the auroral belt at about 4:17 and south again at about 4:28, so that the satellite was north of the center of the auroral belt and near the north magnetic pole at the time the principal bursts were observed. Hence, it could possibly be that each burst marks an encounter of the satellite with denser bands of ionized particles situated along lines of the earth's magnetic field.

A calculation of the radar cross section for this symmetrical burst sequence indicates a value of several square kilometers. Since this area exceeds the physical cross section of the rocket (about 100 square meters) by many orders of magnitude, the implication is that large amounts of ionization were induced by the satellite.

The symmetry of the bursts in the record of Fig. 3 is summarized in Table I. Comparing the burst pairs 33′, 22′, and 11′ we should note that they are symmetrical in time with respect to the center of the sequence to within about 0.2 minute. Another striking feature of the symmetry is that the bursts at about 4:16 and 4:19 are nearly mirror images of the ones at 4:27 and 4:29.

TABLE I

Burst Number	Time of Burst	Time before (−) or after (+) nearest approach
3	4:07.8 A.M.	−15.0 minutes
2	4:15.1	− 7.7
1	4:16.5	− 6.3
0	4:22.8 (nearest approach)	0.0
1′	4:29.3	+ 6.5
2′	4:30.7	+ 7.9
3′	4:37.8	+15.0

July 23, 1958, Observations

As another example of WWV signal bursts associated with a satellite's orbital period, the entire record of the WWV 20-mc signals received on the morning of July 23, 1958, between 12:55 and 8:00 A.M. EST is presented in Fig. 4. This figure is a photograph of the original Esterline-Angus recording with time increasing from right to left. The record has been cut into four equal parts with the center of each section coinciding with the time of the near approach of the Sputnik III instrumented satellite (1958 Delta 2). The vertical line at the center of the figure indicates the approximate time of near approach and the slant line the approximate time of the 40th parallel crossing of the satellite (traveling NNW to SSE). The indications on the record are due to WWV and not to the Sputnik III transmitter (20.005 mc), since, as indicated by the top trace, the deflection dropped to zero level during the WWV off period between 1:45 and 1:49 A.M. even though the satellite was at its point of nearest approach during this interval and readily received on its frequency.

The traces in Fig. 4 are noteworthy since, on four successive passes of the Sputnik III instrumented satellite, there are significant deflections occurring close to the time of the near approach of the satellite to Columbus. Also, there are no deflections of much significance at times other than these.

The geometry of the passes of Fig. 4 was as follows. On the first pass (1:47 A.M.), the satellite (traveling NW to SE) made its near approach over northeastern Canada to the northeast of Columbus. On the second pass, the satellite traveling NNW to SSE made its near approach over the northeastern U. S. to the northeast of Columbus. On the third pass, the near approach of the satellite was to the southwest of Columbus, while on the fourth pass, the near approach was also to the southwest of Columbus but further in this direction.

Doppler Effects

In some CW-reflection observations at The Ohio State University Radio Observatory, it was noted that the correlation of received WWV bursts with artificial satellite passes was improved when the receiver was slightly detuned from the WWV carrier frequency. The record of Fig. 4, discussed in the preceding section, is an example of this effect, the receiver of 5-kc bandwidth having been tuned so that the center of its response was about 2 kc below 20 mc. Subsequent observations with a swept-frequency receiver also resulted in excellent correlations between satellite passes and bursts of WWV signal shifted almost simultaneously to frequencies both above and below the carrier frequency. The observed frequency shift involved at 15 mc was characteristically at least 5 kc. This frequency shift is believed to be a satellite-related Doppler effect. As observed on a loudspeaker, the bursts have no readily distinguished audible tone, but appear to have the characteristics of pure noise.

An example of a series of such Doppler bursts at the time of a satellite pass is shown in Fig. 5. Here the swept-frequency film obtained on 15 mc [Fig. 5(c)] and the upper side-frequency record obtained on 10 mc [Fig. 5(b)] during a pass of the Sputnik III instrumented satellite about 5:55 A.M. (EST) on April 15, 1959 are presented.

The geometry of the pass is indicated in Fig. 5(a) as viewed from a point near the north pole. The locations of Columbus, Ohio and WWV (point of origin of signal) are at the top of the figure on or close to the 40th parallel of latitude. The parallels for 50° and 60° are also indicated. The path of the Sputnik III instrumented satellite is shown along the bottom of the sketch with the satellite direction of travel from right to left (west to east) with times (EST) for the satellite indicated along the path.

The WWV signal received in the frequency band from about 10.001 to 10.003 mc is shown in Fig. 5(b). Time increases from right to left as indicated. Just after Sputnik III had entered the auroral belt, about 5:50 A.M., there was a marked increase in signal reaching its maximum about 5:51 A.M., or one minute before the point of nearest approach to Columbus. Another increase in signal occurred between 5:55 and 5:57 A.M. The recordings of Fig. 5(b) were made using a horizontal half-wave dipole receiving antenna oriented east-west.

Fig. 5(c) shows the simultaneous recording on 35-mm film of the output of a swept-frequency receiver (center frequency 15 mc) between 5:49 and 6:00 A.M. The receiver was swept about twice per second from a frequency of 15 mc minus 4.3 kc (top of the film) to 15 mc plus 4.3 kc (bottom). The receiver bandwidth was about 1 kc. The heavy central trace is the 15-mc carrier of WWV (Washington, D. C.) which was off the air just

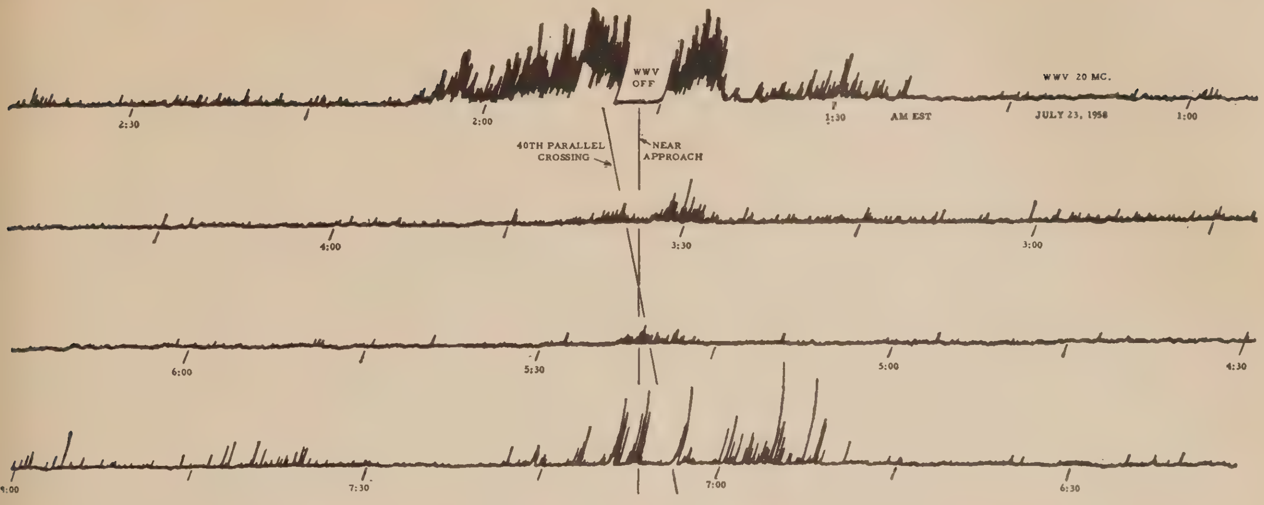

Fig. 4—Records of WWV 20-mc signals recorded between 12:55 and 8:00 A.M. EST on July 23, 1958, showing significant deflections at the times of the near approach of the Sputnik III instrumented satellite on four successive passes.

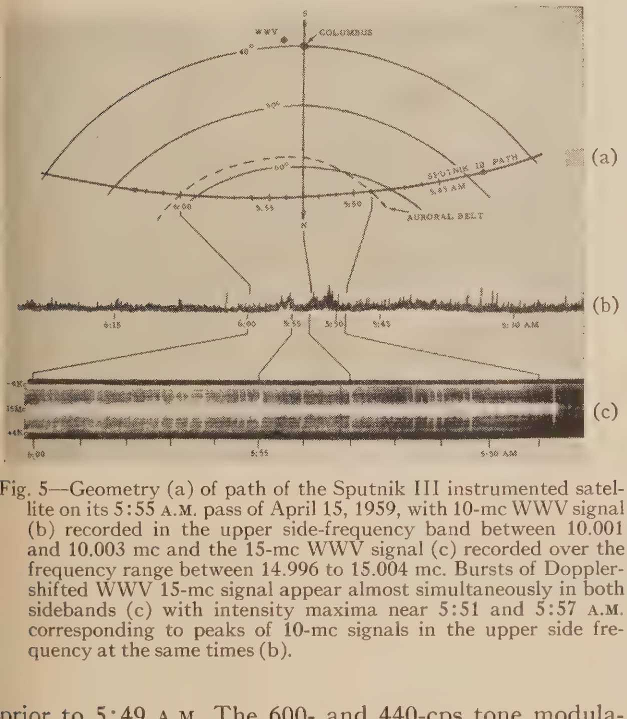

Fig. 5—Geometry (a) of path of the Sputnik III instrumented satellite on its 5:55 A.M. pass of April 15, 1959, with 10-mc WWV signal (b) recorded in the upper side-frequency band between 10.001 and 10.003 mc and the 15-mc WWV signal (c) recorded over the frequency range between 14.996 to 15.004 mc. Bursts of Doppler-shifted WWV 15-mc signal appear almost simultaneously in both sidebands (c) with intensity maxima near 5:51 and 5:57 A.M. corresponding to peaks of 10-mc signals in the upper side frequency at the same times (b).

prior to 5:49 A.M. The 600- and 440-cps tone modulations of WWV, particularly in the upper sideband, are discernible between 5:50 and 5:53 and again between 5:55 and 5:58 A.M. The absence of sideband modulation is also clearly indicated between 5:53 and 5:55 A.M. Of particular interest on this film are the bursts which appear as slightly curved, almost vertical lines. In many cases, these lines extend from the upper- to the lower-frequency limits of the film and perhaps farther. These bursts are especially strong around 5:51 and 5:57 A.M. These times correspond approximately to the times of the signal peaks observed on 10 mc [Fig. 5(b)]. These bursts appear to be Doppler-shifted components of WWV signal which have been deviated by as much as 4 kc or more.

The receiving antenna for the 15-mc observations was a horizontally-polarized directional antenna of the corner reflector type with a physical aperture of 1360 square feet. This directional antenna, with a horizontal half-power beamwidth of about 50°, rotated in azimuth about 6 times per minute. At the instant it passed a fixed reference direction, a fiducial mark was impressed on the film. By interpolation, the direction of arrival of a burst of signal on the film can be determined with an accuracy of about ±30°. Making use of this direction information, we found the azimuthal direction of signal arrival of the bursts in the upper sideband in Fig. 5(c) to be NNW at first, changing gradually to NNE, while in the lower sideband, the direction of the bursts was generally south. Doppler shifts into the upper sideband indicate approach of an object, while shifts into the lower sideband indicate recession. Hence, these observations suggest that the Doppler-shifted signal bursts were produced by reflection of the WWV signal from ionized clouds or streams traveling from the north to the south. The Doppler shifts of at least 4 kc at 15 mc indicate cloud velocities of at least 40 km/second. Since the clouds appear to come from the satellite's general direction, the implication is that they are satellite induced.

In addition to the effects described above, several other Doppler effects have been noted on occasion. One is a coherent Doppler signal changing smoothly in pitch approximately as would be expected for signals reflected from an ionized cloud moving with the satellite. This, however, is a rare effect. A second more commonly observed effect is a quasi-coherent Doppler signal of very irregular characteristics. Such Dopplers have a warbling sound and consist of audio components covering many hundreds of cycles. Such Dopplers may come in groups at the time of a satellite pass and suggest the passage of a number of ionized clouds which may be satellite induced. A third type of Doppler phenomenon occasionally noted is observed as a flutter fading of WWV which begins at a rapid rate, goes through zero beat, and again increases to a rapid rate in a manner analogous to the airplane flutter commonly observed on local TV and FM stations. This effect has been noted at the near approach of artificial earth satellites and is presumably satellite-related since the distance of WWV is too great for an airplane to produce the effect.

Another occasionally observed effect involves a constant pitched tone of the order of 350 cps which is heard superposed on the WWV signal at the time of the pass of a satellite. A frequency of 350 cps corresponds to the gyro-frequency for protons in a magnetic field of 0.23 gauss, a value which occurs in the earth's magnetic field at high altitudes in the lower latitudes. Hence, a proton interaction mechanism is a possible explanation. This constant-pitched tone effect was first reported by Roberts, Kirchner, and Bray[6]. They also were the first to report observing Doppler signals similar to the second type described in the preceding paragraph.

Ionization Mechanisms

The velocity of artificial earth satellites is typically of the order of 7 km/second. Particles initially at rest can be driven ahead of the satellite by an elastic collision at twice this velocity, or about 14 km/second.[5] This is only a fraction of the 40-km/second velocity observed in the clouds discussed in the preceding section. If these clouds are actually satellite induced, as seems to be indicated, then some other acceleration process must be present or else the effect is due simply to an encounter of the satellite with fast corpuscular streams, the particles being driven ahead, deviated, or scattered by the satellite. The noncoherent nature of the reflected signal may be due to such things as turbulence or a random distribution of velocities in the deflected clouds or streams. Assuming elastic collisions and an exactly head-on geometry of encounter, the resulting particle velocity is equal to the incident stream velocity plus twice the satellite velocity.

If the satellite acquires an electric charge, its collision cross section for ionized particles will be increased and the number of particles swept ahead will be larger. Jastrow has indicated that satellites may charge up to potentials as high as 1000 volts.[7] The sweep-up effect of the satellite will also tend to leave a deficiency of particles immediately behind it. For example, if the satellite has a negative charge it will sweep electrons ahead while trailing behind will be an electron hole. This hole in the wake of the satellite constitutes a discontinuity in the medium and may account for significant amounts of scattered signal.

Conclusion

In conclusion, it may be mentioned that many of the best correlations between WWV signal effects and passes of artificial earth satellites have been observed to occur a day or so after large solar flares. At such times the density at high altitudes, particularly in the auroral regions, is increased by the influx of solar particles and it is reasonable to expect that an artificial earth satellite passing through such regions may produce enhanced ionization effects.

Acknowledgment

The assistance of D. J. Scheer in obtaining the 10-mc record of Fig. 5(b) and of R. T. Nash in the construction of the rotating corner reflector is gratefully acknowledged.

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[6] C. R. Roberts, P. H. Kirchner, and D. W. Bray, "Radio detection of silent satellites," *QST*, vol. 43, pp. 34–35; August, 1959.

[7] R. Jastrow, "Artificial satellites and the earth's atmosphere," *Scientific American*, vol. 201, pp. 37–43; August, 1959.

Interplanetary Telemetering*

ROBERT H. DIMOND†

Summary—**The use of telemetry systems over interplanetary distances generates performance requirements more severe than ever before experienced. Full exploitation of the foreseeable state-of-the-art and high over-all operational efficiencies will be essential in fulfilling the requirements of these rigorous standards of performance.**

The problem areas associated with interplanetary telemetry and an approach to the selection of system operating parameters are discussed. The analysis is based on the dividing of operational efficiency into two categories: information efficiency and physical system efficiency. The performance of a typical interplanetary system is analyzed to exemplify the importance of a number of the operating parameters which affect system performance.

INTRODUCTION

THE USE of telemetry systems over interplanetary distances generates performance requirements never before experienced. These rigorous performance requirements will demand full exploitation of the foreseeable state-of-the-art and high over-all operational efficiencies in order to achieve successful interplanetary telemetering or communication. This over-all operational system efficiency may be divided into two categories, one that may be called physical system efficiency, and the other, information efficiency.

Physical system efficiency is determined by such tangible factors as system power and power-conversion efficiency; antenna gains; free space, atmospheric and other signal attenuations and noise at a given radio frequency; receiver and antenna noise levels; and other physical factors.

It is beyond the scope of this report to analyze in great detail the information theory aspect of communication. However, it is a very important consideration and the information efficiency of an interplanetary telemetry system will have a direct bearing on system power requirements. For this reason, a brief discussion of information efficiency is presented, even though this report deals mainly with the physical factors affecting interplanetary telemetry.

INFORMATION EFFICIENCY

Very elementary information theory indicates that systems for other interplanetary communications must employ the same techniques that will be used for telemetry over the same distances. There will be little to distinguish between the signal parameters and much of the apparatus of interplanetary communication and interplanetary telemetry, because of the necessity for both systems to convey the maximum intelligence with the least bandwidth and power demands.

Coding is the essence of applied information theory. When the rate of transmission is predetermined, theory can show the most economic combination of bandwidth and power. However, the current state-of-the-art, limited primarily by technical factors of the coding and decoding devices, is such that no practical coding system has been developed which fully realizes the efficiencies possible in theory. In telemetry, pulse code modulation (PCM) is the practical development which has coincided most closely with theoretical studies of information theory and is one of the most efficient systems in operational use. The bandwidth and information are both linearly proportional to the number of digits, with fixed pulse width, so that the information capacity of a PCM system is proportional to the bandwidth.[1] This is in accordance with the results promised by ideal coding. Conventional PCM, on the other hand, does not make each received information component dependent upon the resultant of a number of signal elements, and in the absence of such an averaging process it cannot work down to a 1:1 ratio of signal power to average noise power. Also, the quantizing and reconstruction of the signal produces some differences between the received information and the original; this difference is called quantizing noise, a function of the coding system itself. Numerous other considerations could be mentioned; however, the above illustrates that even PCM does not represent the optimum coding scheme based on performance theoretically possible.

The preceding discussion has shown that current coding systems are not ideal, and thus new coding systems, approaching more closely to the ideal and therefore more efficient, are bound to be developed to reduce the other system requirements; this is an essential step for reliable interplanetary telemetry and/or communications. It is possible that these new coding techniques will bear little or no resemblence to the currently known techniques. The orthogonal modulation scheme behaves much like the ideal system described by theory and is gaining increased acceptance because of the current interest in high information efficiency.[2] A practical approach to an orthogonal system is the PCM system employing a redundant code, such as the Reed-Muller. The development of several such systems is known to be currently underway.[3,4]

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* Original manuscript received by the IRE, December 2, 1959.

† Research Div., Radiation, Inc., Orlando, Fla.

[1] W. Jackson, "Communication Theory," Academic Press, New York, N. Y.; 1953.

[2] R. W. Sanders, "Communication efficiency of space telemetry systems," *Proc. Natl. Telemetering Conf.*, Denver, Colo., pp. 4–13; May, 1959.

[3] H. N. Putschi and E. Niemann, Jr., "The PCM-PS telemetry system," *Proc. Natl. Telemetering Conf.*, Denver, Colo., pp. 143–150; May, 1959.

[4] R. W. Sanders, "Digilock telemetry system," *Proc. Natl. Symp. on Space Electronics and Telemetry*, San Francisco, Calif., sec. 6.3, pp. 1–10; September, 1959.

Another approach to the problem of increasing the information efficiency of the over-all telemetry system is that of performing in-flight data reduction or processing through the use of statistical techniques.[5] The most useful application of this approach involves the handling of vibration data. In this case, an in-flight real-time spectrum analysis of the data can reduce the modulation rate by 1000:1, since only the characteristics of the spectrum are transmitted.

Table I[6] contains a comparison of four characteristics—threshold carrier signal strength, RF power, information efficiency,[7] and RF bandwidth—for sixteen possible telemetry systems. This table is based on an individual channel output signal-to-noise ratio at threshold of 100 and a total information bandwidth of 1000 cps. The development of the equations used in determining values for the table has been concisely presented.[6]

TABLE I

COMPARISON OF TELEMETRY SYSTEMS

Type	Threshold Carrier Signal Strength	RF Power (Relative to PPM/AM)	Information Efficiency	RF Bandwidth (Kilocycles)
1. PPM/AM	200	1	0.17	76
2. PCM/FM	260	1.7	0.24	18
3. PCM/PM	280	2.0	0.21	20
4. PCM/AM	370	3.4	0.21	18
5. PAM/FM	580	8.3	0.050	85
6. AM/FM	610	9.3	0.045	93
7. PDM/FM	610	9.3	0.045	92
8. PDM/PM	660	11	0.036	110
9. FM/FM	740	14	0.030	140
10. AM/PM	770	15	0.028	150
11. PAM/PM	780	15	0.028	150
12. PDM/AM	790	16	0.035	94
13. FM/AM	830	17	0.055	50
14. FM/PM	860	18	0.023	185
15. PAM/PM	3150	250	0.073	18
16. AM/AM	9600	2300	0.24	9.5

PHYSICAL SYSTEM EFFICIENCY

Establishment of the operating parameters of an interplanetary telemetry system is a rather involved process of trade-offs and compromises. This is because of the many interdependent factors and the need for system optimization. Computer techniques have been logically employed as an aid in determining the optimum system for a particular application.[8]

The fundamental factors limiting the performance[9] of an interplanetary telemetry system may be considered to be system reliability, information capacity, and power consumption for a given physical configuration. Since much has been written regarding component and system reliability it will not be treated in this paper. For the purposes of this discussion, it is assumed that reliability will not limit system performance. Thus, the basic design requirement becomes one of maximizing system operational efficiency. As shown above, operational efficiency may be divided into two categories, physical system efficiency and information efficiency.

Physical system efficiency is determined by the physical factors influencing system performance; in fact, all factors other than information efficiency fall into the category of physical system efficiency. These factors include:

1) Power conversion efficiency.
2) Transmission losses (free-space attenuation, oxygen and water-vapor absorption, line losses, Faraday effect, etc.).
3) External noise (galactic background noise, cosmic and solar noise, man-made noise, etc.).
4) Internal noise (receiver and antenna noise).

The selection of transmission frequency is influenced to some degree by all of the above factors. A transmission "window" in the RF spectrum exists from about 1 to 10 kmc. This is illustrated in Fig. 1 which shows ap-

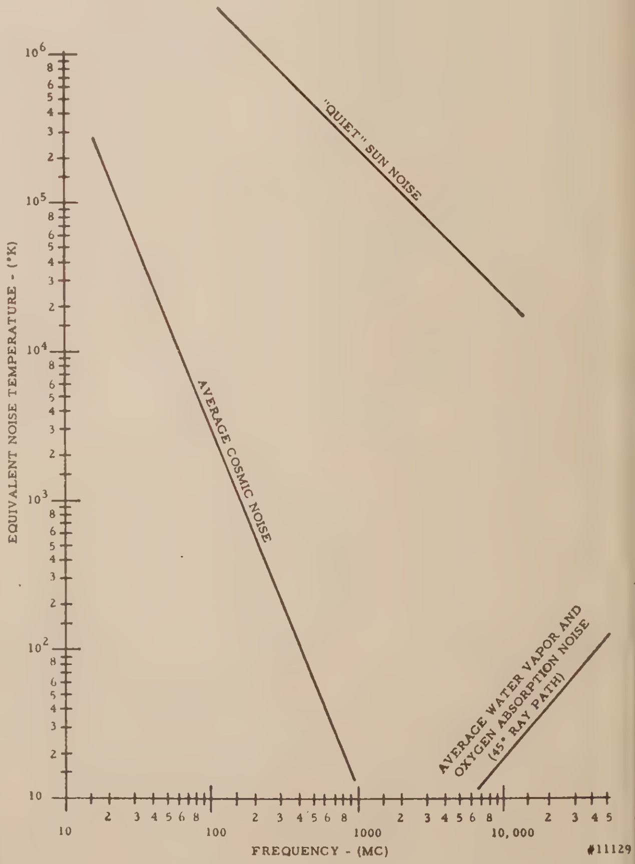

Fig. 1—Ambient space noise vs frequency.

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[5] L. G. Zukerman and I. Ross, "Some coding concepts to conserve bandwidth," *Proc. Natl. Telemetering Conf.*, Denver, Colo., pp. 138–142; May, 1959.

[6] M. H. Nichols and L. L. Rauch, "Radio Telemetry," John Wiley and Sons, Inc., New York, N. Y.; 1956.

[7] Defined here as the ratio of the information capacity of the output signal channel to the information capacity of the modulated signal.

[8] D. R. H. White, "Design and evaluation of space communications systems using computer simulation techniques," *Proc. Natl. Symp. on Space Electronics and Telemetry*, San Francisco, Calif., sec. 1.1, pp. 1–35; September 20–30, 1959.

[9] Performance is defined here as the total information-transmission capability of the system, a function of both information rate and transmission time.

proximate average cosmic and solar noise, and water vapor and oxygen absorption noise as a function of frequency. Certain advantages in operating at higher frequencies are apparent, *i.e.*, reduced cosmic and solar noise, increased antenna gains (for a given size), etc.; however, present receiver and transmitter state-of-the-art necessitates operation near the lower edge of the "window." The *S*-band radio telemetry allocation is very well suited for interplanetary use and much effort is being made to develop new telemetry receivers and transmitters capable of satisfactory and efficient performance at 2250 mc. Sources of noise external to the receiver input, at this frequency, are such that system sensitivity will be normally limited by the receiver input noise, except in the case of maser or parametric amplifiers. Excluding solar noise, the noise of these amplifiers is of the same order of magnitude as the sum of the external noises. However, under certain conditions, a receiving system incorporating a maser amplifier will be limited in threshold sensitivity primarily by external noise.[10]

The minimum level of transmission power required for a specific application is difficult to calculate because of the numerous factors affecting signal propagation. Since little inclusive empirical data are available it is necessary to include a rather large fading margin as a safety factor. Fig. 2 illustrates the free space attenuation between Earth and the near planets. Free-space attenuation is the single factor having the greatest influence on transmission power requirements. Although this is a parameter fixed by the maximum range of each specific application, the more important of the other factors determining transmission power are controllable parameters of the system.

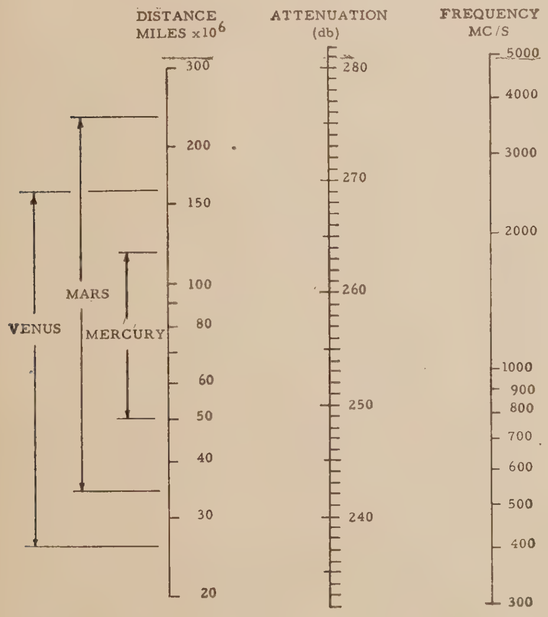

Fig. 2—Nomograph for determination of free-space path attenuation between isotropic antennas.

The bandwidth of the system greatly influences transmission power sensitivity and must be carefully selected because of its wide latitude. A range of 100,000:1 in bandwidth (representing a 50-db power differential) is typical of current communication systems. Because of other existing limitations, it is expected that the desired bandwidth of early interplanetary telemetry systems will be compromised to a value of not more than approximately 500 cps.

Antenna gains will be limited chiefly by the physical size which can be tolerated and the beamwidth limitations imposed by antenna-system tracking capability. The limitations of the vehicle-mounted antenna will be, of course, more severe than those of the ground-based antenna. However, the development of fold-out vehicle antennas and stabilized platforms will allow a substantial improvement over the relatively small antennas which are currently practical. Even a parabolic vehicle antenna of five feet in diameter and having a beamwidth of 6° (at 2250 mc), which now may be feasible, would probably have to be of the fold-out type.[11] Probably the most important limitation restricting the size of a parabolic ground-based antenna is the tolerance to which the reflector can be constructed. Target acquisition becomes increasingly difficult as the beamwidth decreases; but with a known trajectory, acquisition and tracking should be practical with beamwidths of less than 1°.

Receiver detection threshold is a factor which varies within rather narrow limits (compared to the effects of the previously discussed system parameters) and is a function of the type of carrier modulation and detector. Correlation-detection techniques have been applied to FM receivers as phase-locked detectors with threshold improvements in the order of 6 db. An analysis of this aspect of the system logically falls into the category of information theory.

The system power requirement (and thus power conversion efficiency) is another essential consideration. This will determine the capacity of a system which can operate from a given energy source, or conversely, the energy required for a particular system and operating time. Power conversion efficiency of a transmitter can vary from 5 to almost 50 per cent, depending upon the modulation requirements, whether it employs tubes or solid-state components, operating frequency, power output, etc. Over-all telemetry system power requirements are such that the rest of the system may require as much, or more, power than transmitters operating at levels below about 50 watts. Solid-state systems will be very valuable in minimizing power requirements for interplanetary missions. It is expected that even the first interplanetary systems will be almost entirely transistorized. In the future, highly efficient solar cells may completely remove the current power requirement restrictions.

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[10] R. Hansen, "Low noise antennas," *Microwave J.*, vol. 2, pp. 19–24; June, 1959.

[11] H. Scharla-Nielsen, "Space ship telemetering," presented at Natl. Symp. on Telemetering; April, 1957.

It can be seen from the preceding discussion that physical system efficiency or over-all telemetry system performance, exclusive of coding or modulation considerations, is influenced by a large number of factors of varying importance. Each one of these factors must be carefully analyzed with respect to the total system and mission to enable design parameters to be established which will yield the most efficient practical interplanetary telemetry system.

Factors Influencing System Performance

Transmission losses are generally thought of as including free-space attenuation, water-vapor and oxygen absorption, etc. It is frequently more convenient to consider many of these factors in terms of equivalent noise temperature, rather than in terms of power loss. This allows transmission loss factors and noise sources (receiver, cosmic, solar, etc.) to be treated in the same manner. This approach is especially valuable when dealing with maser and parametric amplifiers. The performance of these devices is best measured by techniques which yield performance figures in terms of equivalent input noise temperature. Also, noise figures of less than one decibel can be obtained.[12] These are more meaningful when expressed as noise temperatures.

Fig. 3 illustrates the effect of receiver, or receiving-system, effective input noise power (expressed as noise figure or effective noise temperature) on noise level over a range of receiver bandwidths. The basis for this information is shown by the following analysis.

The noise figure of a network is defined as

$$F = \frac{\frac{S}{N}\text{ (input)}}{\frac{S}{N}\text{ (output)}} \tag{1}$$

where S = signal power and N = noise power.

Theoretical ambient noise power is defined as KT_0B, where K = Boltzmann's constant (1.38×10^{-23} joules/°K), $T_0 = 290°$K, and B = bandwidth. By defining the effective internally generated noise power, referred to the network input, as P_n, the equation for noise figure[13] can be expressed as

$$F = \frac{\dfrac{S}{KT_0B}}{\dfrac{GS}{GKT_0B + GP_n}} = 1 + \frac{P_n}{KT_0B} \tag{2}$$

where G = network gain; or,

$$P_n = (F-1)KT_0B. \tag{3}$$

Expressing P_n as KT_eB, where T_e is defined as the effective input noise temperature of the network (internally generated and referred to the input), (3) becomes

$$KT_eB = (F-1)KT_0B,$$

or

$$T_e = (F-1)T_0, \tag{4a}$$

also

$$F = 1 + \frac{T_e}{T_0}. \tag{4b}$$

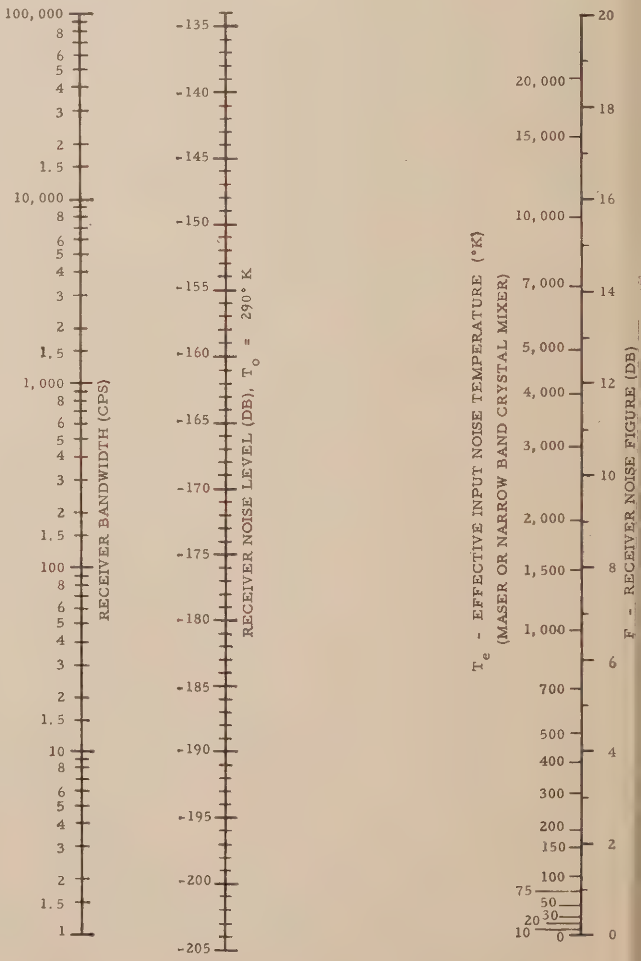

Fig. 3—Nomograph for determination of receiver noise level.

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[12] S. Perlman, *et al.*, "Concerning optimum frequencies for space vehicle communications," *Record of Natl. Symp. on Extended Range and Space Communication*, Washington, D. C., pp. 24–31; October, 1958.

[13] H. I. Ewen, "A thermodynamic analysis of maser systems," *Microwave J.*, vol. 2, pp. 41–46; March, 1959.

The total noise power, P, of a network is composed of the sum of the theoretical ambient noise power and the internally generated noise power. When these are added [(3) plus KT_0B], the following familiar expression is obtained:

$$P = (F - 1)KT_0B + KT_0B,$$

or

$$P = FKT_0B. \qquad (5)$$

Substitution of (4b) in (5) for F illustrates that noise temperatures T_0 and T_e may be added to obtain the total noise power.

$$P = \left(1 + \frac{T_e}{T_0}\right)KT_0B,$$

or

$$P = (T_0 + T_e)KB. \qquad (6)$$

It can be seen from (4)–(6) that in a noiseless network where $F=0$ db, or 1, $T_e=0$ also, so that $P=KT_0B$.

Fig. 1 shows that water vapor and oxygen absorption noise is not a significant factor below 10 kmc when the ray path is 45°, or more, from the horizon. As the transmission path approaches the horizon attenuation can increase by a factor of two; however, at a frequency of 2250 mc, this attenuation is negligible. Fig. 1 also shows that cosmic noise is insignificant at 2250 mc. The equivalent noise from specific radio stars will be higher but the average value is considerably less than 10°K. It can be seen that the sun is a strong noise source throughout the entire RF "window." Even though solar noise decreases at higher frequencies, the current state-of-the-art is such that an attempt to operate at the apparently ideal frequency of 8–10 kmc would not be practical. Also, the sun as a noise source can be avoided since its angular width is small. At 60 mc this angle may approach 1° and at 30 kmc the angle is approximately 0.5°. Thus, it can be seen that the radio frequency of 2250 mc represents a logical compromise between present communication techniques and galactic noise levels.

Free space attenuation between Earth and Venus, Mars, and Mercury can be determined from Fig. 2. As an example, the free-space attenuation for a typical interplanetary distance of 60 million miles (approximate median distance to Mars, Venus, and Mercury) is 260 db at 2250 mc.

With the successful application of maser and parametric amplifiers, the receiver is no longer the factor which limits system sensitivity, even at microwave frequencies. Antenna noise temperatures (largely ignored until recently) may be as high as 150°K and frequently limit system sensitivity when the above amplifiers are employed. Noise sources include the atmospheric, cosmic, and solar noise levels previously discussed. Additional noise results from the side and back lobes, as well as the main beam, "seeing" land and even sea areas as thermal reservoirs.[10] Also, losses in the antenna feed and reflector add to the noise temperature. Radomes represent another noise source, because of losses in the dielectric and sometimes high ambient temperatures.

Analysis of Transmission Power Requirements

Using the typical interplanetary mission of Venus probe as an example, RF power requirements have been calculated based upon the following parameters.

Distance (nominal) $=60\times10^6$ miles
Radio frequency $=2250$ mc
Transmitting antenna:
  Diameter $=5$ feet
  Gain $=29$ db
  Beamwidth $=6°$
Receiving antenna:
  Diameter $=100$ feet
  Gain $=54$ db
  Beamwidth $=0.3°$
  Noise temperature $(T_{LB})=55°)$ K[14]
Passive element losses $(L_0)=1$ db (approximate).

A composite three-term expression[13] for the effective noise temperature of the system is given by:

$$T_s = \underset{1)}{[T_G + T_{BL}]} + \underset{2)}{[(L_0 - 1)T_0]} + \underset{3)}{[T_eL_0]}. \qquad (7)$$

1) Temperature contributions from sources outside the signal path.
2) Radiation temperature of composite losses, amplified by the magnitude of the composite loss.
3) Effective temperature of the active circuits, amplified by the magnitude of the composite loss forward of these circuits. Where

$T_G=$ galactic background radiation field, cosmic noise.

$T_{BL}=$ produced as a result of the inefficiency of the antenna in directing its entire pattern into the forward direction (back lobes intercepting the earth as a thermal reservoir).

$L_0=$ composite losses of the passive hardware of the system.

$T_e=$ effective temperature of the active circuits.

$T_0=290°$K.

Solving (7) yields a value of T_s, from which an overall system noise level can be calculated. Using the given system parameters and a nominal sky temperature of

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[14] Cold sky at S band.

10°K (excludes the sun and discrete radio stars, such as Centaurus, etc.), T_s becomes:

$$T_s = [10 + 55] + [(1.259 - 1)290] + [25 \times 1.259]$$
$$= 172° \text{ K}.$$

Taking the necessary bandwidth (B) as 300 cps and solving (6) yields a value for P as follows:[15]

$$P = (290 + 182)(1.38 \times 10^{-23})(300) = -177 \text{ db}.$$

Fig. 3 can be used to obtain this value by our drawing a line between T_e of 172°K and B of 300 cps. This line intersects the receiver noise level scale at −177 db.

Required transmitter power may now be determined by the following procedure. A 20-db fading margin, or required SNR, is used to provide what should be an ample safety factor.

Receiving system noise level	−177 dbw
Required SNR	20 db
Receiving system sensitivity	−157 dbw
Receiving antenna gain	− 54 db
Path attenuation at 60×10^6 miles	260 db
Required radiated power	49 dbw
Transmitting antenna gain	− 29 db
Required transmitter power	20 dbw (100 watts)

This approach can be somewhat simplified through the use of Figs. 3 and 4. Fig. 4 also can be used to determine the gain of a parabolic antenna at various frequencies.

Basic transmission power required (Fig. 4) (with $D = 60 \times 10^6$ miles and $f = 2250$ mc)	56 dbw/cps bw
Correction for 300 cps bw	25 db
System noise factor (Fig. 3) (with $T_s = 172°$K)	2 db
Required SNR	20 db
Receiving antenna gain	−54 db
Required radiated power	49 dbw

CONCLUSIONS

The present state-of-the-art in radio telemetry is such that successful interplanetary telemetering can be achieved; however, to keep the transmission power requirements within reasonable limits, information rates will have to be low (possibly 500 cps) and the system will have to be carefully designed for maximum operational efficiency. It has been shown how the over-all operational system efficiency may be divided into two distinct categories, information efficiency and physical system efficiency, to facilitate analysis of system performance.

Applied information theory can show how the greatest information per unit bandwidth and power, or information efficiency, can best be obtained. Coding techniques are the products of applied information theory. Even the best of current coding schemes, and their variations, do not reflect the information efficiency possible in theory. Therefore, much is yet to be accomplished in this field and these results will appear as new coding schemes more closely following the level of efficiency promised by theoretical studies.

Factors influencing physical system efficiency are many and varied. The more important factors include: system power conversion efficiency, transmission losses, external noise, and internal noise. These factors, along with transmission frequency, are all to some degree interrelated. External noise sources (cosmic, solar, etc.) are distributed such that they limit the usable interplanetary transmission frequencies to a lower value of about 1 kmc. The upper frequency limit of about 10 kmc is determined by water vapor and oxygen absorption. Thus a transmission "window" exists between the approximate frequencies of 1 and 10 kmc.

The development of very low noise amplifiers, such as the maser and the parametric, represents a breakthrough of major significance to extended range communications. The receiver itself, previously the weakest link in receiving system sensitivity, has now become one of the strongest. Noise temperatures of 25°K (corresponding to a noise factor of substantially less than 1 db) are now being obtained with maser amplifiers, and future masers are expected to operate at noise tempera-

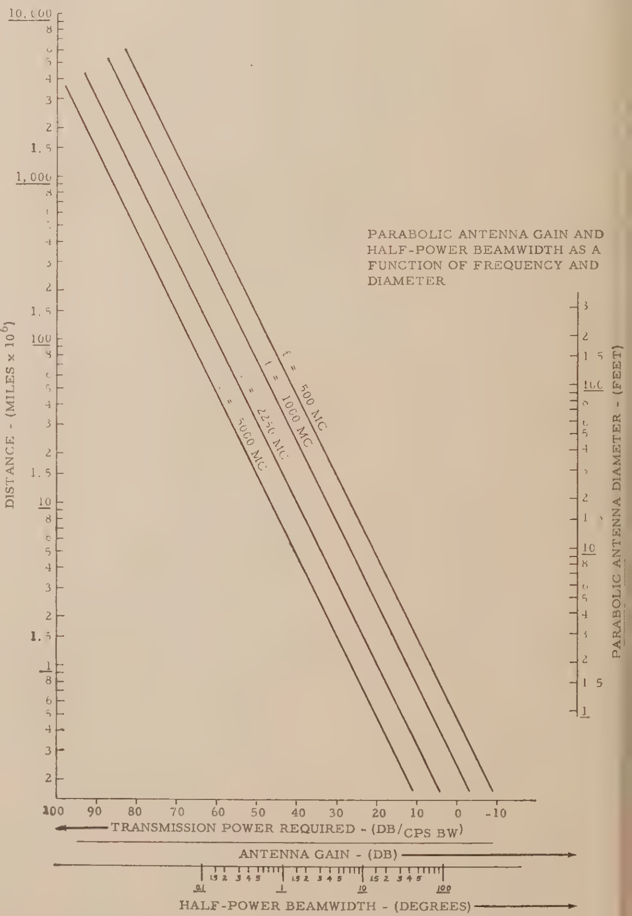

Fig. 4—Transmission power required per cps beamwidth at given frequency and distance. Isotropic antennas: $F = 0$ db; $S/N = 0$ db.

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[15] Since T_s is substituted for T_e, P becomes the total noise power of the system.

tures of 5°K. Parametric amplifiers are reported to be capable of noise temperatures of 75°K (approximately 1 db) at 1 kmc. Noise sources external to the receiver itself generally have now become the limiting factors of receiving system sensitivity. Thus, these external noise sources, including the antenna itself, are now being considered with an interest heretofore nonexistent (except possibly in the field of radio-astronomy).

The hypothetical system analyzed in the previous section is admittedly rather optimistic in some respects, especially in antenna characteristics. However, it is likely that steerable ground and vehicle antennas as described will be utilized in the near future. The system bandwidth of 300 cps is a limiting factor in information capacity, and it is expected that this situation will exist for some time until more efficient coding methods are put into practice and more efficient solar power sources are developed.

There can be no doubt, however, in spite of the problems involved, that reasonable amounts of intelligence can be telemetered back to Earth from the near planets by the use of techniques presently available. The approach to the problem presented in this report is by no means all-inclusive but it should give the reader a better understanding of this branch of communications for interplanetary applications.

Space Telemetry Systems*

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Summary—**This paper presents some of the problems which are faced in the field of space telemetry, and gives a few examples of the approaches used in attempts to solve these problems to date.**

The different types of information to be transmitted back to receiving stations on the earth from satellites and space probes are discussed. The telemetry systems (FM/FM, FM/AM, PCM/PM, etc.) which have been used in various experiments of this type are described, along with some typical performance figures for some past payloads.

The paper is concluded with a discussion of the problems to be faced in future experiments.

Introduction

THIS PAPER presents some of the problems which are faced in the field of space telemetry, and gives examples of the approaches which have been used to solve these problems. A summary of the characteristics of the telemetry systems used in the nonmilitary satellites and space probes is also given.

The launching and successful orbit of the first manmade earth satellite marked the beginning of a new era in the field of telemetry. For years man had used remotely located instruments to measure events and physical phenomena, first with "hard-wire" links from inaccessible or physically dangerous locations and later with the use of radio links. With the entry into space, man now faces a new field and new problems. This newly opened region, beyond the protective blanket of atmosphere, contains many unanswered questions. Measurements must be made of the space environment near the atmosphere to confirm or refute ideas based on extrapolated data and scientific conjecture. In addition, there is knowledge to be gained about the moon and the deep reaches of outer space.

Only after considerable knowledge has been gained about radiation levels, micrometeorite densities, temperature balance, and many other environmental factors will it be reasonably safe to send a man into this unexplored frontier. When manned space flight begins, telemetry will be required to bring back data on man's physiological and psychological conditions in his weightless environment.

Space Systems vs Conventional

In the testing of aircraft and in many ground-based systems, flexibility, ease of adjustment, ease of maintenance, and long life were factors of primary importance. With the advent of the missile age, size and weight of equipment took on new meaning and emphasis. It was found that in most missile operations, the life of the telemeter unit was limited to a single flight, and the addition of each pound of weight resulted in a serious degrading of the missile performance. Hence, a great amount of time and effort went into finding ways to improve the effective bandwidth utilization and reliability while reducing weight at the expense of long operating life and ease of operation.

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* Original manuscript received by the IRE, November 23, 1959.

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With the entry into the space age another re-evaluation of telemetry requirements must be made. Missile flights were usually limited to minutes, or possibly to a few hours for some air-breathing cruise-types, but satellites and space probes will have lifetimes of from weeks to years. Reliability and long life cannot be overemphasized because of the difficulty and great expense of each project. Power vs bandwidth problems become even more critical at the increased distances. Weight has increased in importance because of the penalty in performance—decreased height of orbit in the case of a satellite—which results from even ounces of weight. A pound of weight in the satellite is equivalent in lost performance to several hundred pounds of weight in the earlier stages of the launching vehicle.

Power requirements must be reduced to the absolute minimum because of the effects of overheating and the extra weight of the power supply, whether it be chemical batteries or solar cells.

The environment encountered in space flight introduces other problems. Heat must be controlled by a careful balance between radiation and absorption; there is no atmosphere available for convection cooling nor is there a heat-sink available. Erosion of surfaces, particularly those of solar cells, must be checked. If little or no protective coating is required, a considerable weight saving can be effected. The effect of high energy radiation upon components cannot be ignored.

Types of Telemetry Information

Information to be transmitted to the ground falls into many categories. Temperatures at certain critical positions inside the payload, as well as the temperature outside the payload, are needed for future design information. Radiation of many types must be identified and measured in order to determine its effect upon future operations. Micrometeorite particles must be studied to determine size, density, and hazard potential. In fact, all of the environmental conditions are different from anything previously encountered.

As space exploration continues there will be a requirement to transmit pictures of the surfaces of the moon, and of Venus, Mars, and other planets back to earth. The astronomers will observe the stars from an orbiting observatory outside the earth's atmosphere, marking the first time that man has studied the radiation of the stars without the earth's atmosphere as a filter. Pictures of the earth taken from several hundred miles altitude will give meteorological information regarding cloud formations to increase the accuracy of long-range weather forecasting.

When the first manned space flights are made, physiological data must be under almost constant surveillance by medical personnel.

System Requirements

The cost of operations and the nature of the experiments place an imposing list of requirements on the telemetry system. Accuracy of the over-all system, which could be rather crude at first, must be improved to permit accurate measurements of brightness levels of stars, and other high resolution measurements in the order of 0.1 per cent. Bandwidths of 3 to 6 mc will be needed if high resolution TV pictures are to be transmitted in real time. The range of operation for the radio link will vary from a few hundred miles for a low-altitude, short-lived satellite to many millions of miles for deep space shots. Length of operating life will vary widely for different operations. For instance, low-altitude satellites may last only a few hours, while high satellites or space probes may continue to function for years.

The telemetry system used on many payloads should be extremely flexible both in the type of data handled and in data handling rate. A variable data transmission rate will allow more efficient use of radiated power where channel information rates and distance vary over wide limits. For example, with highly eccentric satellite orbits, velocity and necessary information rates are at a minimum when the satellite is at its maximum distance from the earth.

The type of data will vary in some experiments when a single transmitter is used for more than one purpose such as for alternately sending environmental data and a television picture. In addition, the system should be able to switch on command from a low radiated power mode to a high power mode as a deep space probe travels farther away from the earth, or as the bandwidth of the information is increased.

Space Telemetry Systems Previously Used

Table I lists some of the nonmilitary space probes and satellites which were fired previous to the writing of this paper. It provides a ready comparison of pertinent telemeter data, including frequency, modulation scheme, power, and weight, as well as orbital or range data. The subcarrier bands listed are the standard Inter-Range Instrumentation Group (IRIG) bands.

Telemeter transmitters of 10 to 60 mw power output have provided quite adequate signals for data reception to ranges of 2000 to 3000 miles with bandwidths of 2 to 3 kc. Most payloads have used more than one transmitter in order to provide a certain amount of redundancy and to provide additional data channels.

While it is apparent that several different modulation schemes have been used, it should be pointed out that, with the exception of the Vanguard series, telemetry systems have adhered closely to IRIG standards.

Many of the payloads were designed and fabricated on a short time schedule and as a result the organizations supplying them used the telemetry systems with which they were most familiar and which at the same time appeared to be adequate for the scientific experiment. These systems include FM/FM, FM/AM, FM/PM, PCM/PM, and the Vanguard PDM-FM/AM.

TABLE I

Name	Frequency (mc)	Transmitter Power	Type Modulation	Amount of Carrier Modulation	Antenna Type	Radiation Polarization	Subcarrier Bands‡ (If IRIG FM/FM)	Approximate Transmitter Life	Type Power Supply	Weight of Batteries (pounds)	Apogee (miles)	Perigee (miles)	Launch Vehicle
Explorer I	108.00	10–20 mw	FM/PM	0.7 radian (rms)	Dipole	Linear	2, 3, 4, 5	$3\frac{1}{2}$ months	Mercury batteries	2.2	1,573	224	Jupiter C
	108.03	10 mw	FM/AM	50 per cent	Turnstile	Circular	2, 3, 4, 5	$\frac{1}{2}$ month		2.1			
Explorer III	108.00	10 mw	FM/PM	0.7 radian (rms)	Dipole	Linear	2, 3, 4, 5	$2\frac{1}{2}$ months	Mercury batteries	2.2	1,746	121	Jupiter C
	108.03	*60 mw	FM/AM	50 per cent	Dipole	Linear		$1\frac{1}{2}$ months		3.1			
Explorer IV	108.00	10 mw	FM/PM	0.3 radian (rms)	Dipole	Linear	1, 2, 3, 4, 5	$1\frac{3}{4}$ months	Mercury batteries		1,380	163	Jupiter C
	108.03	30 mw	FM/AM	100 per cent	Dipole	Linear	1, 2, 3, 4, 5	$2\frac{1}{4}$ months					
Explorer VI (Paddlewheel)	108.06	*60 mw	FM/FM		Two monopoles	Linear	1, 2, 3, 4, 5, 8	1 month	Solar cells and chemical batteries	17	26,000	156	Thor-Able
	108.09	*60 mw	FM/FM		Two monopoles	Linear	1, 2, 3, 4, 5, 6						
Vanguard I	378.00	* 5 watts	PCM/PM		Two monopoles	Linear							
	108.00	10 mw	FM	Approx. 6 kc	Turnstile	Circular		19 days	Mercury batteries	10.5 ounces	2,453	407	Vanguard
Vanguard II	108.03	5 mw	FM	Approx. 6 kc	Dipole	Linear		Years	Solar cells				
	108.00	10 mw	FM	Approx. 6 kc	Turnstile	Circular		27 days	Mercury batteries	10.5 ounces	2,061	350	Vanguard
Vanguard III	108.03	* 1 watt	AM/AM	60 per cent				18 days		$8\frac{1}{2}$			
	108.00	30 mw	PDM-FM/AM	100 per cent	Turnstile	Circular		90 days Predicted	Silver—zinc	22.35†	2,330	318	Vanguard
Pioneer I	108.03	*80 mw	AM	100 per cent	Turnstile	Circular							
	108.06	300 mw	FM/PM	1.0 radian	Dipole	Linear	1, 2, 3, 4, 5, 6	43 hours	Mercury batteries		Altitude 70,700	Space probe. Did not orbit	Thor-Able
Pioneer II	108.09	100 mw	FM/PM	1.0 radian	Dipole	Linear	1, 2, 3, 4, 5, 6	Life of probe					
	108.06	300 mw	FM/PM	1.0 radian	Dipole	Linear	1, 2, 3, 4, 5, 6	Life of probe	Mercury batteries		Altitude 963	Space probe. Did not orbit	Thor-Able
Pioneer III	108.09	100 mw	FM/PM	1.0 radian	Dipole	Linear	1, 2, 3, 4, 5, 6						
	960.05	180 mw	FM/PM	0.79 radian (peak)	Conical payload served as the antenna	Linear	1, 2, 3	38 hours	Mercury batteries	6.6	Altitude 63,580	Space probe. Did not orbit	Juno II
Pioneer IV	960.05	180 mw	FM/PM	0.79 radian (peak)	Conical payload served as the antenna	Linear	1, 2, 3	90 hours	Mercury batteries	6.6	In orbit around the sun. TM data and tracking were continuous to 400,000 miles.		Juno II

* Transmitters have command features.

† This battery weight includes power for the magnetometer polarizing field.

‡ IRIG FM/FM Subcarrier Bands (cps) (in part): 1) 400, 2) 560, 3) 730, 4) 960, 5) 1,300, 6) 1,700, 7) 2,300, 8) 3,000.

While some satellites have used continuous transmission of data, it has been found more practical in other instances to store data for subsequent readout by radio command. By this approach it is possible to economize both on transmitter power and on the number of ground receiving stations. A tremendous number of stations would be required to give full-time global coverage of satellite operations.

Data storage has taken two general forms. On Explorer III and Vanguard II, data for a complete orbit were recorded on tape and played back upon command during passage over a Minitrack station. Vanguard III used magnetic-core storage devices in which the flux level was a function of the peak value of current flow in the input winding. Two such devices were switched alternately between storage and readout conditions once each orbit when the satellite passed from shadow into sunlight, thus providing a reading of the maximum input encountered on the previous orbit.

VANGUARD SYSTEM

The PDM-FM/AM system which was designed for use on the later Vanguard satellites during the International Geophysical Year will also be used on some of the satellites to be placed in orbit with the Scout vehicle. Forty-eight information channels are nominally provided consisting of 16 FM tone bursts and 32 PDM time-interval channels. Information is carried by three methods:

1) frequency of each tone burst;
2) duration of each burst;
3) time interval between bursts.

Both the data sampling rate and the number of data channels are readily changed. Data sampling rates may be changed by varying the maximum time duration of the samples; two or more channels may be paralleled (supercommutation) to increase sampling rates on particular inputs as necessary. The system is so designed that the number of data channels may be readily changed in multiples of three by the removal or addition of circuit sections as needed. The system's 108-mc transmitter is amplitude modulated.

A typical Vanguard telemetry system, including transmitter, encoder, and batteries, weighed approximately six and one-half pounds and occupied a volume of 510 cubic inches. The basic 48-channel encoder weighed approximately 3.2 ounces and consumed 12 mw of battery power. The 108-mc transmitter was designed to radiate 80 mw of power. The low power requirements permit continuous operation for a period of three to four weeks on the mercury batteries contained in the package size and weight given above. In the typical Vanguard system the tone bursts were in the frequency range of 5 to 15 kc, with the time durations of the bursts and times between bursts falling between 5 and 30 msec. Thus, all 48 channels were sampled three to four times per second depending upon the values of the input signals to the PDM channels. The encoder was designed to accommodate variable voltages (0 to 5 volts, variable currents (typically one milliampere full scale) or variable resistances (5000 ohms maximum).

FM SYSTEM

The FM/FM, FM/PM, and FM/AM systems used on the Explorer and Pioneer satellites and space probes have used standard IRIG, $7\frac{1}{2}$ per cent frequency modulated subcarrier channels. The outputs of the subcarrier oscillators have been combined as in a standard FM/FM telemetry system and this combined output has been used to modulate the transmitter carrier frequency. Pioneers have all used phase modulation of the carrier, while Explorer payloads have used either frequency, phase, or amplitude carrier modulation. The receiving equipment of the original ground stations was designed with narrow bandwidths in order to provide minimum noise for maximum range of telemetry coverage. This narrow bandwidth capability has required that the subcarrier oscillators be confined to the lower frequency bands, as shown in Table I.

The telemetry system used on the Explorer I was typical of those used on the Explorer I, III, and IV satellites. A volume of 120 cubic inches contained the complete telemeter unit. Weight of the electronic payload was 11.8 pounds, and total equipment weight was 18.2 pounds, including the structure and antenna. Four subcarrier oscillators operating in bands 2, 3, 4, and 5 were used. The data, which included skin and internal temperatures, cosmic ray measurements, and micrometeorite impact data, were duplicated on two transmitters. One at 108.00 mc was a 10- to 20-mw transmitter employing phase modulation and the second was a 60-mw amplitude modulated transmitter. The 10-mw transmitter was powered by six RM-42 mercury cells and the 60-mw transmitter by 24 RM-42 mercury cells.

In the Pioneer I and II space probes the electronic payload weighed 22.5 pounds, including two telemetry transmitters, command receivers, antenna, batteries, and other electronic equipment. One transmitter radiated 100 mw; the other, 300 mw. On command from the ground station the 300-mw transmitter functioned as the return link of a two-way Doppler system. Both transmitters were phase modulated with information from 6 subcarrier oscillators in bands 1 through 6. Power was obtained from mercury batteries which were expected to provide a life of 100 hours for the low-power transmitter and of 10 to 15 days for the high-power transmitter.

The Pioneer III and IV space probes used a single FM/FM transmitter operating at 960.05 mc with a radiated power of 180 mw. Three subcarrier oscillators n bands 1, 2, and 3 were used. Power was obtained rom 6.6 pounds of mercury batteries. The payload of Pioneer IV was tracked and telemetry data received ntil battery exhaustion occurred 82 hours after launch-ng, at a distance of 407,000 miles from the earth.

PCM System

The PCM/PM system is used on the Explorer VI Paddlewheel) satellite. This system transmits frames f information which repeat periodically. Each frame onsists of eleven words, with one word being used for ynchronization and ten words for data. Each word is nade up of twelve binary bits, two bits for word ynchronization, and ten bits for data. In order to con-erve power when rapid data transmission rates are not equired, the system is designed to operate at rates of , 8, or 64 bits per second. A command signal from the round turns on the telemeter link and determines the it rate. The RF carrier is phase modulated.

Soviet Telemetry

The satellites put into orbit by the Soviet Union have sed transmitter frequencies of 20.05 mc and 40.01 mc. These low frequencies have been useful in certain radio ropagation studies and have provided signals in fre-uency bands covered by the radio receivers used by adio "hams" throughout the world. This latter fact was great factor in increasing and stimulating worldwide nterest in the first launching. In addition to telemetry ransmitters in the 20-mc band, the two Soviet lunar robes used a transmitter operating at 183.6 mc.

The Soviet satellites have used both chemical bat-eries and a combination of chemical batteries and solar ells to power their telemetry systems. Due to the rela-ively heavy payloads available to them, they have sed higher transmitter powers than most U. S. satel-ites. This power coupled with the lower frequencies has iven telemeter coverages over quite large areas from ach receiving station.

In contrast to the Soviet systems, U. S. satellites ave operated on a higher frequency to take advantage f the increased accuracy of radio tracking obtainable t the shorter wavelengths, and have concentrated on btaining the maximum amount of scientific informa-ion possible within the lesser weight limits available for ayloads.

Data Collection

Telemetry data collection for the nonmilitary pro-ram has been accomplished primarily by facilities wned or contracted for by the National Aeronautics nd Space Administration, such as the Minitrack net-ork and university groups in the United States and broad; facilities under the cognizance of Department of efense groups; the 250-foot-diameter radio telescope t Jodrell Bank, England; and the facilities of various olunteer groups.

Minitrack Network

The Minitrack network is composed of ten stations which were set up under Project Vanguard to track and record data for satellites fired in low inclination orbits during the IGY. Now a facility of the NASA, this network uses radio interferometry techniques to determine satellite angular position vs time data which are accurate to within 20–200 seconds of arc and 1 msec of time. Tracking capability now exists at 108 mc for U. S. satellites with some secondary capability at 40 mc for use with Soviet satellites. Facilities are presently being installed for use on the new 136–137-mc band allocated for space communications.

Present Minitrack tracking and telemetry stations are located at Blossom Point, Md.; San Diego, Calif.; Fort Myers, Fla.; Antigua, West Indies; Quito, Ecuador; Lima, Peru; Antofagasta, Chile; Santiago, Chile; Woomera, Australia; and Esselen Park, South Africa. Four new stations being added to provide increased coverage for polar orbiting satellites will be located in Minnesota, Alaska, Newfoundland, and Europe.

The telemetry receivers in operation at each of the Minitrack stations are of an amplitude modulation superheterodyne type and were originally intended to receive the Vanguard telemetry signals during the IGY program. Adapters have been added to the receivers for the 108-mc band to permit the reception of frequency modulated and phase modulated signals. These receivers have three bandwidths, selected as desired, of 31, 5.8, and 3.4 kc. Sensitivities at these three bandwidths are approximately −120, −127, and −130 dbm, respectively. Antennas with a gain of approximately 12 db are used for telemetry reception. In addition to the 108-mc band, five stations are equipped to receive and record amplitude modulated telemetry data on 20 and 40 mc. Esselen Park is equipped to handle telemetry at 20 mc only and has no 108-mc capability.

All stations are equipped with command transmitters which are used in conjunction with receivers in certain satellites to turn on data storage devices and telemetry transmitters.

Future Space Telemetry

Even at this early stage in the exploration of space, the need for many advancements in the fields of telemetry and communications is recognized. Programs such as the meteorological satellite will require transmission of high resolution pictures of the earth's surface. Lunar and planetary exploration programs will require a similar capability over much greater ranges. These and other programs such as active repeater communications satellites will require wide bandwidth data transmission with reliable operation over long periods of time. Astronomical and other sophisticated scientific studies bring additional requirements. Briefly stated, we must develop a capability for reliable transmission of data at much greater rates, over tremendously increased distances and, in many cases, for longer periods of time.

Several possible approaches to solving these problems exist, all of which must be thoroughly explored and exploited.

The "brute force" approach to the problem is to increase the effective transmitter power in order to allow wide bandwidth operation with reasonable signal-to-noise quality. Transmitter power alone is not a practical solution, however. If 5 watts of radiated power are necessary to transmit certain data to the earth from the moon, about 50,000 watts will be required to produce the same results from Venus at its closest approach to the earth. Thus, although higher powered, more efficient transmitters will be developed, further increases in effective transmitted power must come from the use of high-gain transmitting antennas on the vehicle. The development of higher-gain, more efficient ground-based receiving antennas is also desirable.

New and improved power sources will be required because of increased power drain and longer periods of operation. In addition to these factors, solar cells on interplanetary missions will drop to about 45 per cent of normal output at Mars and to about 4 per cent at Jupiter.

In addition, reductions in system noise and improvements in system efficiency are also necessary. Range of operation will be increased by the use of low-noise amplifiers in the ground receiving equipment. Parametric and maser amplifiers are now in their infancy and show great promise along these lines. New improvements of these amplifiers can be expected to be in field use within a relatively short period.

It will be possible to conserve bandwidth by transmitting information on a reduced time scale when information is not required in "real time." However, in all cases a careful application of information theory will be required to determine the best telemetry systems to establish maximum information capacity. Perhaps the greatest step forward in the field of space telemetry will be brought about by careful application of modern information theory to the development of more efficient communications systems.

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Signal-to-Noise Considerations for a Space Telemetry System*

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Summary—A signal-to-noise comparison is given between the pulse-frequency channels and the pulse-width channels for the FM/PDM-AM telemetry system. It is shown that the pulse-frequency channels have either a higher signal-to-noise ratio or greater information rate capability than the pulse-width channels.

INTRODUCTION

A CONSIDERABLE effort is being expended towards the development of rocket vehicles capable of propelling large payloads into space. As the payload grows larger, the need for miniaturization decreases and is supplemented by redundancy to improve reliability; however, for some time to come there will be a need for light-weight, low power-drain telemetry systems. A current example of this need is illustrated in the Scout rocket program.

The Scout vehicle is a relatively inexpensive four-stage rocket capable of orbiting payloads in the 150-pound category. This vehicle will be used on a cooperative basis by scientists of other nations. Because of the restricted weight limitations of the payload, it is imperative that the telemetry electronics compose only a small portion of the instrumentation. There are several types of existing systems which meet this requirement, and most of these have enjoyed success in orbiting vehicles.

In general, for those systems in which multiple-channel simultaneous data is needed, at least two different systems are in use. The early Explorer and Pioneer telemetry employed FM subcarrier oscillators which phase-modulated the transmitter carrier. The subcarrier frequencies were derived from the Inter-Range Instrumentation Group Standards and occupied the lower bands. Vanguard III used a different type of system which was designed primarily to fit a particular set of scientific experiments. It is the purpose of this paper to explore the signal-to-noise considerations for this latter type of telemetry, since little information on the subject has appeared in print.[1,2]

PRINCIPLE OF OPERATION

Vanguard III is the combination of two earlier scientific satellites of the Vanguard series: the proton-precessional magnetometer and the X-ray-environmental satellite. The magnetometer has a separate transmitter, and a four-second turn-on is accomplished by command transmitters at each ground station. The X-ray and environmental portion is transmitted continuously except for the four-second interval during command. The circuitry for the continuous telemetry has been described in the literature; therefore, only a discussion of its operation will be given here. The telemetry encoder shown in Fig. 1 has a 48-channel capacity and weighs 3.2 ounces. The power drain is 10 milliwatts.

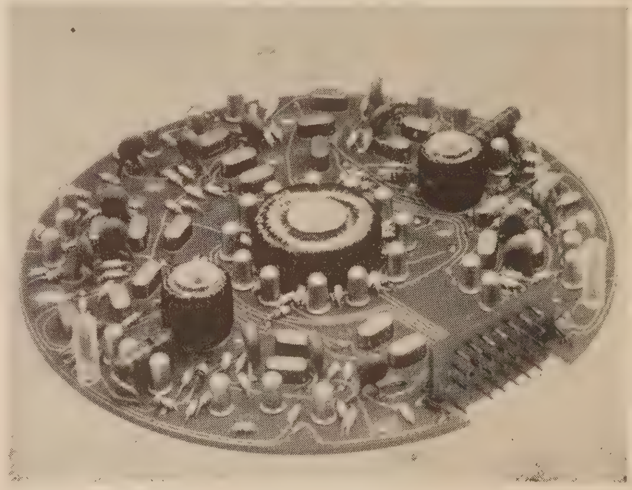

Fig. 1—View of telemetry encoder.

The basic system employs sixteen subcarrier oscillators which are sampled sequentially in time. Each oscillator is deviated over a frequency range of from 5 to 15 kc by its input signal voltage. The composite signal as fed to the transmitter would appear as a train of audio pulses, the frequency of each being representative of a signal level in a particular channel. It is also possible to modulate the pulse widths of each of the audio pulses in proportion to other signal inputs; likewise, the time lengths between adjacent pulses may be modulated in proportion to still other signal inputs, which would extend the number of channels available. As in other systems, the principle of super- and subcommutation may be employed either to increase or decrease the number of channels. Supercommutation is employed in the illustration in Fig. 2 which shows a typical frame of the telemetered signal from a satellite such as Vanguard III. The maximum length of a pulse or the separation between pulses is twenty milliseconds, while the minimum length is four milliseconds. One of the pulse lengths is maintained fixed and longer than any

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* Original manuscript received by the IRE, December 2, 1959.

† Natl. Aeronautics and Space Admin., Washington, D. C.

[1] R. W. Rochelle, "Earth satellite telemetry encoding system," *Elec. Engrg.*, vol. 76, pp. 1062–1065; December, 1957.

[2] N. W. Matthews, *et al.*, "Cyclops cores simplify earth-satellite circuits," *Electronics*, vol. 31, pp. 56–63; February, 1950.

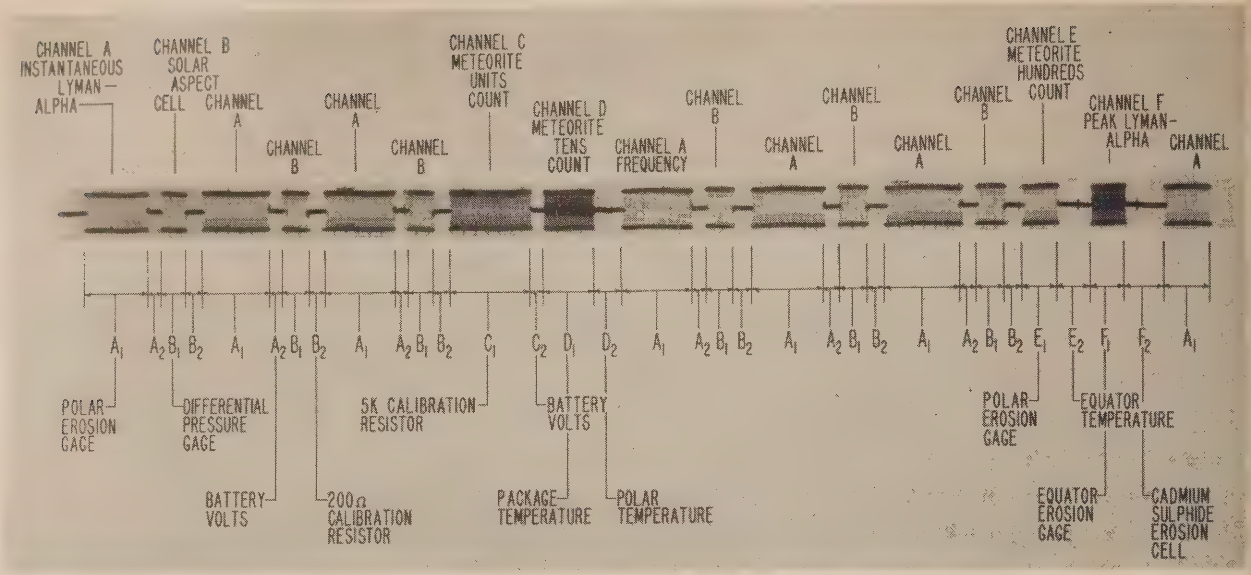
CHANNEL A INSTANTANEOUS LYMAN-ALPHA
CHANNEL B SOLAR ASPECT CELL
CHANNEL A
CHANNEL B
CHANNEL A
CHANNEL B
CHANNEL C METEORITE UNITS COUNT
CHANNEL D METEORITE TENS COUNT
CHANNEL A FREQUENCY
CHANNEL B
CHANNEL A
CHANNEL B
CHANNEL A
CHANNEL B
CHANNEL E METEORITE HUNDREDS COUNT
CHANNEL F PEAK LYMAN-ALPHA
CHANNEL A
A1 A2 B1 B2 A1 A2 B1 B2 A1 A2 B1 B2 C1 C2 D1 D2 A1 A2 B1 B2 A1 A2 B1 B2 A1 A2 B1 B2 E1 E2 F1 F2 A1
POLAR EROSION GAGE
DIFFERENTIAL PRESSURE GAGE
BATTERY VOLTS
200Ω CALIBRATION RESISTOR
5K CALIBRATION RESISTOR
BATTERY VOLTS
PACKAGE TEMPERATURE
POLAR TEMPERATURE
POLAR EROSION GAGE
EQUATOR TEMPERATURE
EQUATOR EROSION GAGE
CADMIUM SULPHIDE EROSION CELL

Fig. 2—Typical telemetered signal showing channel allocations.

of the rest, so that synchronization upon decoding may be effected.

The information content of this type of signal is based on the frequency of a pulse being proportional to a signal input and also the duration of a pulse and the time between pulses being proportional to signal inputs. This characterizes two basic types of measurement: frequency and time. Both of these measurements will be described in detail and signal-to-noise error ratios derived for each.

MEASUREMENT OF PULSE FREQUENCY

The frequency measurement for a single channel may be thought of as a "window" looking in on the signal. The window is "open" only during the times that a particular channel is being sampled. The exact length of time that the "window" is held open is, of course, determined by a signal in the pulse-width channel. If the signal is changing during the time that the "window" is open, the change in pulse frequency is proportional to the slope of the signal at that point while the average frequency denotes the magnitude of the signal. Thus, at each sample point it is possible to get not only the magnitude of the signal but the slope as well. Knowing the slope at each sampling point is equivalent to doubling the sampling rate. The result, then, is that the information bandwidth of the frequency channels is effectively doubled.

To optimize the signal-to-noise ratio, the pulse is passed through a filter. There are several factors which determine the proper width of the filter. First, consider a pulse frequency equal to 10 kc and a width of 10 milliseconds. Suppose that it is desired to detect only the presence or absence of the pulse. The power spectrum of the pulse is given by:

$$\Omega(\omega) = \int_{-\infty}^{+\infty} \epsilon^{-j\omega t} e(t)\,dt$$

$$= K\left[\frac{\sin\left[(\omega-\omega_0)T/2\right]}{\omega-\omega_0} + \frac{\sin\left[(\omega+\omega_0)T/2\right]}{\omega+\omega_0}\right]. \quad (1)$$

The major part of the energy is contained in the band plus and minus $1/T$ cps, so that a filter with a bandpass of 200 cps should reproduce the pulse with only a small loss of detail. The rise and fall time (for a simple *LC* filter) is $1/(2\pi \times 200)$ second or 0.8 millisecond. The bandwidth may be narrowed further. In three time constants the response is up to 95 per cent. With this criterion,

$$3\tau = 10 \text{ milliseconds},$$

or

$$\tau = 3.3 \text{ milliseconds},$$

then

$$f = \frac{1}{2\pi \times 3.3}\,\text{kc} = 48 \text{ cps}.$$

There would be, of course, 5 per cent crosstalk into the next pulse channel, which could cause an error. However, if the object is to detect only the presence or absence of a pulse, this could be a satisfactory bandwidth.

The question can now be raised, "How accurate may the frequency of the single pulse be, read in the presence of noise?" There are two ways to approach the problem. As long as the signal amplitude is greater than the noise, a counter may be used to measure the frequency directly, provided that the bandwidth of the filter is wide enough to allow the output to reach steady state. In the example of a 10-kc pulse 10 milliseconds long, a 200-cps filter would be quite adequate to allow the switching transient to damp out. The counter could count for almost the full 10 milliseconds. If the bandwidth were narrowed substantially, there might not be enough counting time in the 10 milliseconds, due to the longer switching transient. It would take 10 milliseconds for the output to build up to essentially full amplitude, at which time the pulse amplitude drops to zero. The filter will continue to ring in a damped oscillation for another 10 milliseconds at the resonant frequency of the filter.

In the presence of noise, the error percentage in the frequency measurement would be:

$$\text{error percentage in frequency} = \frac{N}{S} \times \frac{100}{2\pi f_1 T_1} \qquad (2)$$

where

N = rms noise voltage
S = signal voltage
f_1 = pulse frequency
T_1 = pulse duration.

If the frequency of the pulse is known to have a finite number of discrete values, a bank of narrow filters, each tuned to one of the discrete frequencies, may be used to improve the signal-to-noise ratio. Here the problem reduces to determining only the presence or absence of a signal. The outputs of the filters can be added in logic circuitry in such a way that the greatest signal is the only one present in the combined output.

MEASUREMENT OF PULSE WIDTH

In this telemetry system the widths of the pulses are modulated; this has a definite effect on the minimum width of filter that can be used. The minimum pulse width is four milliseconds. From the frequency measurement viewpoint the bandwidth should not go below 500 cps because of error introduced by switching transients; however, in reading out the pulse-width information, it is seen that a much wider bandwidth is needed. Consider again a 10-kc pulse 10 milliseconds long. After this is passed through a filter, the leading and trailing edges of the pulse will have a rise and fall time dependent on the filter bandwidth; the narrower the bandwidth, the longer is the rise and fall time. The pulse duration is defined as the time between midpoints of the rise and fall portions. In-phase noise will cause an apparent shift in the midpoint of the leading and trailing edges of the pulse. The amount of the shift is calculated much in the same manner as the effect of quadrature noise on the frequency measurement was calculated. The per cent of error in the width measurement is given by:

$$\text{error percentage in pulse width} = \frac{N}{S} \times \frac{100}{2\pi B_2 T_2} \qquad (3)$$

where

N = rms noise voltage in passband B
S = signal voltage
B_2 = bandwidth of filter
T_2 = maximum change in pulse duration.

Although the expression is almost identical to (2), N contains a factor of $\sqrt{B_2}$ which can be cancelled by the B_2 in the denominator, making the per cent of error inversely proportional to $\sqrt{B_2}$. Increasing B_2 will decrease the per cent of error until the bandwidth becomes so wide that the rise and fall occur in a few cycles of the pulse frequency, f_1. Taking B_2 at this point to equal the pulse frequency, f_1, the ratio of (3) to (2) gives the improvement factor of the frequency measurement over the pulse-width measurement. The improvement factor is found to be

$$\eta = \sqrt{\frac{f_1}{B_1}}$$

where

η = improvement factor
f_1 = pulse frequency
B_1 = bandwidth of frequency measurement.

CONCLUSION

If the same bandwidth is used for both the width and the frequency measurements, there is little difference in the signal-to-noise ratios. In poor signal-to-noise conditions the bandwidth for the frequency measurement may be narrowed down to get an effective improvement. For this reason signals which may not need the higher frequency response or accuracy are placed on the width channels. The frequency channels have the advantage of giving both the magnitude and the slope of the signal for the same number of sampling points.

The signal is adaptable to either single-sideband or double-sideband suppressed carrier modulation to gain a threshold improvement over amplitude modulation.

The best signal-to-noise ratio is obtained when the oscillators are limited to a finite number of discrete frequency levels and no width channels are used. This type of system would have the same noise threshold as pulse code modulation, with the added advantage that the digits are not restricted to a binary system. The advantage is gained at the expense of distributing the signals over a wider bandwidth, even though the predetection bandwidth is the same in both cases.

Telemetry Bandwidth Compression Using Airborne Spectrum Analyzers*

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Summary—**In practice, most missile test signals requiring wide-band telemetry channels are high-frequency random signals obtained from vibration accelerometers, etc. However, their information content is contained in their slowly-varying statistical parameters. Considered are the unique problems associated with first extracting the spectral density plot of high-frequency random signals (one of the most useful of the statistical parameters), and then presenting this to the telemeter. Design formulas are derived showing the interrelationship between the parameters of the random signal and the characteristics of the telemetry. Formulas indicating the tremendous improvement in bandwidth efficiency are also given.**

INTRODUCTION

A STUDY of telemetry systems used in connection with missile or aircraft development indicates that most of the information being gathered is slowly-varying in nature. Temperatures, pressures, body attitudes, etc., are typical of such quantities. Because these are slowly-varying, they require only a narrow bandwidth in the telemetry link; only a small portion of the data gathered requires wide bandwidth. Most of the wide-band signals that must be telemetered are derived from vibration or acoustic pickups. Now, while their component frequencies may extend to very high limits, the actual information in the signals is contained in their statistical properties, which are varying at a rate comparable to that of the temperatures, pressures, etc., that make up most of the data. It seems, therefore, to be poor telemetry practice to use up almost all of the available bandwidth for these wide-band channels. This bandwidth inefficiency can be eliminated by using small light-weight airborne analyzers, to do the statistical analysis immediately during the flight of the vehicle under study.

This paper discusses the fundamental design considerations of a statistical analyzer to extract in real time the spectral density plot of a random signal (one important type of statistical information) and to present this as a slowly-varying dc voltage to the missile, satellite, or aircraft telemeter. A number of basic problems of some novelty in spectrum analyzer design are introduced by this unique combination of a spectrum analyzer and telemeter. For instance, the conditions of flight are likely to change relatively quickly. Thus, the equipment must be able to do a complete analysis quite quickly. The slow analyzing rate permitted by the continuous recycling of the same data through the analyzer cannot be used. Another problem arises from space, weight, and environmental considerations. The bulky and critically-adjusted components found in most laboratory spectrum analyzers are not acceptable in an airborne telemetry unit subjected to a military or space-flight environment.

It was to explore solutions arising from such unique problems that most of the work outlined in this paper was undertaken.

GENERAL DESCRIPTION OF SPECTRUM ANALYZER

The basic element of the power spectrum analyzer is a narrow band-pass filter, used to divide the frequency bandwidth of the input signal into small intervals. The output of the filter is fed into a detector, which attempts to obtain the average value of some predetermined function of the power, for a specific period of time, in a narrow band of frequencies about the center frequency of the filter. If the bandwidth of this analyzing filter were decreased indefinitely (and the averaging time were also increased indefinitely) the measurement would yield the theoretical power spectral density.

There are two general types of spectrum analyzers: swept types, where one filter is used to sweep over the band of frequencies to be analyzed; and multichannel types where the frequency band is covered by a number, depending on the resolution required, of contiguous filters. The filters are the heaviest and most bulky of the components involved.

The swept type is chosen for study because of its size and weight advantage. Its adaptability to airborne use is enhanced by the fact that it supplies data to the telemeter in a serial fashion. It can be considered to be composed of four principal sections: a swept oscillator-modulator; a narrow-band filter; a squaring circuit; and a detector and integrator.

Let us consider, as an example, a spectrum analyzer which covers the frequency spectrum from 100 cps to 2000 cps. The purpose of the oscillator-modulator is twofold. First, it generates a local signal which is time-modulated by a linear sweep, varying the frequency from 5000 to 7000 cps. Second, it heterodynes this signal with the input signal. A balanced modulator which suppresses the carrier frequency is usually used. As a result, the input signal spectrum is translated along the frequency axis. This frequency translation has the effect of passing the spectrum through the pass band of the analyzing filter at a uniform rate. The oscillator is a symmetrical multivibrator, since the output waveform lends itself ideally to use in a switchtype modulator. In order to insure that the filter analyzes each frequency

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* Original manuscript received by the IRE, December 2, 1959; revised manuscript received, January 5, 1960.

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interval for equal periods of time, the linearity of the sweep is carefully maintained.

A squaring device is necessary to convert the filter output into a signal proportional to power density, if this conversion is required. A linear detector yields root power density. The output signal from the detector is a dc voltage proportional to the desired function of the spectral density. Superimposed on this is a very large random signal, which must be reduced or removed by a low-pass averaging filter if accuracy is desired.

The present study of the analyzer system consists principally of an investigation into its sources of error when the analyzer is operated in real time as part of a telemeter. The problems in mating the analyzer to the conventional telemeter data-gathering system are also covered.

THE ACTION OF THE ANALYZING FILTER

Effect of Sweep Speed

The first problem is that of establishing the general conditions for the satisfactory operation of the analyzing filter, when a rapid analysis is to be carried out. This rapid analysis is one of the principal differences between the present application and the slowly-sweeping laboratory installations. It is important to adhere to major filter properties and to ignore minor refinements. We then stand a good chance of simplifying the filter. Weight and size will thereby be reduced.

An upper limit is set by the bandwidth of the filter, on the speed with which it can be permitted to sweep the spectrum.

It is well known [1] that a tuned circuit of bandwidth B cps, when a sinewave is impressed on it at its center frequency, will build up to the steady-state condition with a time-constant T_b given by

$$T_b = \frac{1}{\pi B}\cdot \tag{1}$$

As the analyzer sweeps across the band, the output of the filter due to a new spectral component must reach steady-state in a small fraction of the time during which the component is in the filter. Otherwise, filter transient conditions will introduce a serious error. The limitation imposed on the rate of frequency sweep, q(cps/sec), can be established by considering the bandwidth B_n (cps) of any "resonant" peak in the spectrum of the random signal.

Obviously, we must keep

$$\frac{B_n}{q} \gg \frac{1}{\pi B} \tag{2}$$

or

$$q \ll \pi B \cdot B_n. \tag{3}$$

If this relationship is maintained, the output of the filter can be considered solely as the steady-state spectral density of the original wave as operated on by the filter pass band. This is important in subsequent work.

Chang [2] considers the effect of the filter sweeping through the spectrum at such a rate that the filter time-constant T_b cannot be completely ignored. He derives results of extreme interest; the filter peak response is depressed by a factor:

$$g = \frac{1}{\sqrt[4]{1 + \left(\frac{4}{\pi}\frac{q}{B^2}\right)^2}}\cdot \tag{4}$$

The bandwidth of the filter can be considered as increased by the fraction: $1/g^2$; the center of the filter has shifted by $(4q/B)$ cps. From (4), Chang's criterion for not altering the filter performance is given by

$$q \ll B^2. \tag{5}$$

It will be shown later, that, for accurate measurement, we must have

$$B_n > B.$$

Thus, inequality (5) is a more severe restraint on q than inequality (3). With this restraint, the filter output can be analyzed as a steady-state phenomenon.

Blurring Error

The basic purpose of the spectrum analyzer is to detect the total power (or root power) coming out of the filter. This total power is to be used as a measure of the power spectral density at the filter center frequency. Thus, if there is lack of symmetry in the power contributions obtained from each side of the filter center frequency, an error results. This error is called the blurring error. To hold the blurring error to a minimum, the filter response must be kept symmetrical. But the symmetry of power contributions from the two sides of the filter response can still be upset if the power spectral density changes across the filter band. Chang [2] shows how the blurring error can be estimated. It is given by

$$e_b = \frac{P_w - P_a}{N} \tag{6}$$

where

P_a = the actual power out of the filter,

P_w = the power out of the filter assuming a white-noise source, adjusted to have the same spectral density at $f = f_0$ as P_a, and

N = a factor to normalize the power response of the filter, given by (9) below.

By use of the mean-value theorem, we can transform (6) into

$$e_b = \frac{B^2}{8}\cdot\frac{J}{N}\cdot\left[\frac{d^2P(f)}{df^2}\right]_{f_0} \tag{7}$$

where

$P(f)$ = the power spectral density under study in watts per cps,

TABLE I

Case	Filter Type	$\lvert Z(u)\rvert$	N	J	J/N	$(B/B_s)^2$
I	Single-tuned	$\frac{1}{\sqrt{1+u^2}}$	π	∞	∞	1
II	Double-tuned (isolated)	$\frac{1}{1+u^2}$	$\pi/2\left(\frac{B_s}{B}\right)$	$\pi/2\left(\frac{B_s}{B}\right)^3$	2.42	0.414
III	Triple-tuned (isolated)	$\frac{1}{(1+u^2)^{3/2}}$	$3\pi/8\left(\frac{B_s}{B}\right)$	$\pi/8\left(\frac{B_s}{B}\right)^3$	1.28	0.26
IV	Rectangular	$\begin{cases}1(-1<u<+1)\\0(u>+1)\\\quad(u<-1)\end{cases}$	$2\left(\frac{B_s}{B}\right)$	$2/3\left(\frac{B_s}{B}\right)^3$	0.33	1

f_0 = the center-frequency of the analyzing filter (cps), and

$$J = \int_{-\infty}^{+\infty} x^2 \cdot Z^2(x) \cdot dx \tag{8}$$

$$N = \int_{-\infty}^{+\infty} Z^2(x) dx. \tag{9}$$

$Z(x)$ is the filter selectivity function (*i.e.*, its amplitude response characteristic).

$$x = \frac{2(f - f_0)}{B}. \tag{10}$$

The ratio (J/N) is calculated for a number of filter types. The results are summarized in Table I; the amplitude characteristics are expressed as $Z(u)$, where

$$u = \frac{2(f - f_0)}{B_s}. \tag{11}$$

B_s is the single-stage bandwidth of the multi-stage filter systems listed.

It is obvious that the blurring error is reduced as the skirt attenuation of the filter becomes more rapid. Only simple filters can be considered as practical for an airborne analyzer. However, a single-tuned filter seems less than acceptable. There is only a minor improvement to be made by using a triple-tuned (isolated) filter over a double-tuned (isolated) one. The rectangular filter is listed only to illustrate the effect of skirt attenuation.

In order to establish the practical impact of the blurring error, let us take (7) and apply it to an isolated spectral peak in the spectral density distribution. Let us assume this peak is obtained by a procedure similar to passing white noise through a single-tuned filter.

Let P_n be the power density at the center frequency f_n of the peak, in watts per cps. Then the spectral density in the neighborhood of f_n can be given by

TABLE II

Case	$\left.\frac{e_b}{P_n}\right]_{f_n}$ for $B=B_n/3$	Minimum Acceptance (B_n/B)	
		$e=10\%$	$e=5\%$
I	∞	∞	∞
II	24%	5.0	7.0
III	14%	3.5	4.8

$$P = \frac{P_n}{1 + y^2} \tag{12}$$

where

$$y = \frac{2(f - f_n)}{B_n}. \tag{13}$$

(B_n is as before the bandwidth of the spectral peak.) Combining (7) and (12) gives, for the blurring error at f_n

$$\left.\frac{e_b}{P_n}\right]_{f_n} = \frac{J}{N}\cdot\left(\frac{B}{B_n}\right)^2. \tag{14}$$

In Table II are calculated the values of (14) for the case when $B = \frac{1}{3}B_n$ for the practical filters of Table I.

Limiting e_b at f_n to a given value establishes the sharpness of the spectral peak that can be handled. Suppose an error limit of $e/100$ is established, then

$$\frac{B_n}{B} \geq 10 \cdot \sqrt{\frac{J}{Ne}}. \tag{15}$$

Calculated in Table II are the limiting ratios established by (15) for the practical cases discussed.

Ten per cent error is quite acceptable for the type of measurement we are making here. The above results indicate that the blurring error only becomes serious when B_n approaches $3B$.

The above calculations compute blurring error as a fraction of the spectral density being measured. However, another effect of the blurring error is the widening of any spectral peaks under study. This widening effect can best be evaluated by using in place of (12) the following formula for the peak:

$$P = P_n \exp\left[-\left(\frac{f-f_n}{m}\right)^2\right]. \tag{16}$$

Hence,

$$\frac{e_b}{P_n} = \frac{-1}{4}\cdot\frac{J}{N}\cdot\left(\frac{B}{m}\right)^2 \cdot\left[1-2\left(\frac{f-f_n}{m}\right)^2\right]\exp\left[-\left(\frac{f-f_n}{m}\right)^2\right]. \tag{17}$$

By putting $P = P_n/2$ in (16), we can obtain B_n:

$$B_n = 2\cdot\sqrt{k_0}\cdot m \qquad (k_0 = \log_e 2). \tag{18}$$

By using, in place of P_n,

$$P_n' = P_n - \left| e_b \right|_{f=f_n} \tag{19}$$

and solving for the value of $(f-f_n)$, making

$$P + e_b = \frac{P_n'}{2}, \tag{20}$$

we obtain the apparent bandwidth B_n' of the spectral peak. The error in bandwidth is therefore

$$\Delta B_n = B_n' - B_n. \tag{21}$$

Let us proceed to do this:

$$P_n' = P_n\left[1 - \frac{1}{4}\cdot\frac{J}{N}\cdot\left(\frac{B}{m}\right)^2\right].$$

To solve for $(f-f_n)$ in (20), we must have:

$$\left(\frac{f-f_n}{m}\right)^2 = \log_e 2 + \log_e\left(1 - \frac{J}{4N}\cdot\frac{B^2}{m^2} \cdot\left[1 - \frac{2(f-f_n)^2}{m^2}\right]\right) - \log_e\left(1 - \frac{1}{4}\cdot\frac{J}{N}\cdot\frac{B^2}{m^2}\right). \tag{22}$$

Assuming $B < B_n$ under all conditions, (22) can be approximated as:

$$\left(\frac{f-f_n}{m}\right)^2 = \log_e 2 + \frac{(f-f_n)^2}{2m^2}\cdot\frac{J}{N}\left(\frac{B^2}{m^2}\right). \tag{23}$$

Or,

$$(f-f_n) = \sqrt{k_0}\cdot m\cdot\frac{2}{\sqrt{1 - \frac{J}{2N}\cdot\frac{B}{m^2}}} \tag{24}$$

$$(f-f_n) = B_n\cdot\left[1 + \frac{Jk_0}{2N}\left(\frac{B}{B_n}\right)^2\right]. \tag{25}$$

In this equation we have solved for B_n'. Hence, from (21), we can write that the apparent increase in bandwidth is given by

$$r_b = \frac{\Delta B_n}{B_n} = \frac{Jk_0}{2N}\cdot\left(\frac{B}{B_n}\right)^2 = H\left(\frac{B}{B_n}\right)^2. \tag{26}$$

Table III gives the value of H for the practical filters considered in Table I.

TABLE III

Case	$H(B<B_n)$
I	∞
II	0.83
III	0.44

Eq. (26) evaluates the blurring error as a degradation of the filter resolution. The results tabulated in Table III indicate that we can go to smaller ratios of (B_n/B) for the same percentage error, when we consider the blurring error along the frequency axis, rather than as a power density error. A 10 per cent degradation in resolution does not occur until B_n is decreased to as low as $B_n = 2B$.

Once again, the practical blurring error improvement of the more sophisticated circuit of Case III over that of Case II is quite significant.

PROPERTIES OF THE FILTER OUTPUT SIGNAL

It is valid here to assume that the analyzing filter is symmetrical about its center-frequency f_0. It is also valid to assume that its bandwidth satisfies

$$B \ll f_0. \tag{27}$$

Hence the following well-known formula can be used to represent the signal out of the filter:

$$\begin{aligned} V(t) &= C(t)\cos 2\pi f_0 t + D(t)\sin 2\pi f_0 t \\ &= A(t)\cos\left[2\pi f_0 t + \phi(t)\right] \end{aligned} \tag{28}$$

where $C(t)$, $D(A)$, $A(A)$, $\phi(t)$ are slowly-varying functions. $C(t)$ and $D(t)$ are independent.

If the filter is driven by white noise of power spectral density P_1, the autocorrelation function of $V(t)$ is given by

$$R(\tau) = \int_0^\infty P_1 H^2(f)\cdot\cos 2\pi f\tau\cdot df \tag{29}$$

where $M^2(f)$ is the filter power spectral operator.

RIPPLE ERROR USING A SQUARE-LAW DECTECTOR

The filter output signal is applied to a detector, where rectification occurs. The dc level obtained is therefore a measure of the spectral density at f_0. The detector law determines whether power or amplitude, or indeed some other spectral density, is obtained. Due to the beating of the signal components in the detector, a noise signal occurs at the output of the detector, superimposed on the desired dc level. Filtering this new noise spectrum is needed to obtain a useable result. Indeed, the amount of noise passed by the post-detection filter determines the accuracy with which the desired dc output can be read at any instant.

It is desired here to study both outputs of the detector: the dc signal, and the noise spectrum. The post-detector smoothing problem posed by the short sweep time of the analyzer can then be explored. The effect of the design of the frequency-selecting filter on the detector noise spectrum (and hence on the accuracy) will also be established for several common types of filter.

Suppose the signal of (28) and (29) is applied to a detector obeying the law

$$V_0(t) = V^2(t). \tag{30}$$

It can be shown [4] that

$$\overline{V_0(t)} = \overline{C^2(t)} = \overline{V}. \tag{31}$$

Let $P_0(f)$ be the power spectral density of the detector noise. Then it can also be shown [4] that

$$P_0(f) = 4\int_0^\infty (\overline{V})^2 R(\tau) \frac{\cos \pi f\tau}{\cos 2\pi f_0\tau}\, d\tau. \tag{32}$$

The easiest filter shape to deal with is the rectangular one of Case IV, Table I. This filter, though not practical in this application, will be taken as reference in studying the detector problem. This does not mean that such a filter is the most desirable, as is sometimes implied. It is chosen here as standard primarily because its properties are widely quoted, and it can serve as a base for comparison. With such a filter, we can write:

$$\text{a)}\quad \overline{V}_0 = P_1 B \tag{33}$$

$$\text{b)}\quad R(\tau) = P_1 \frac{\sin \pi B\tau}{\pi B\tau} \cos 2\pi f_0\tau \tag{34}$$

$$\begin{aligned}\text{c)}\quad P_0(f) &= 0 && f \geq B\\ &= \frac{2(\overline{V}_0)^2}{B}\cdot\left(1 - \frac{f}{B}\right) && 0 \leq f \leq B.\end{aligned} \tag{35}$$

If now the simple single-tuned filter (Case I of Table I), is used, we get

$$\text{a)}\quad \overline{V}_0 = \frac{\pi}{2} P_1 B \tag{36}$$

$$\text{b)}\quad R(\tau) = P_1 e^{-\pi B\tau}\cdot\cos 2\pi f_0\tau \tag{37}$$

$$\text{c)}\quad P_0(f) = \frac{2}{\pi}\,\frac{(\overline{V}_0)^2}{B}\cdot\frac{1}{\left(1 + \frac{f^2}{B^2}\right)}. \tag{38}$$

If a synchronously-tuned pair is used (Case II of Table I):

$$\text{a)}\quad \overline{V}_0 = \frac{\pi}{4} P_1 B_s \tag{39}$$

$$\text{b)}\quad R(\tau) = \frac{\pi}{4} P_1 B_s (1 + \pi B_s\tau)\cdot e^{-\pi B_s\tau}\cdot\cos 2\pi f_0\tau \tag{40}$$

$$\text{c)}\quad P_0(f) = \frac{2}{\pi}\cdot\frac{(\overline{V}_0)^2}{B_s}\left[\frac{\cos a}{(1 + f^2/B_s^2)^{1/2}} + \frac{\cos 2a}{(1 + f^2/B_s^2)} + \frac{\cos 3a}{2(1 + f^2/B_s^2)^{3/2}}\right] \tag{41}$$

where

$$\tan a = f/B_s. \tag{42}$$

An examination of the equations from (33) to (41) reveals two interesting facts:

1) The desired dc output $\overline{V}_0$ is greater by approximately 50 per cent when the simple tuned circuits are used than when the rectangular filter, as defined in Table I, is used.
2) White noise through a rectangular filter detected in a square-law detector has no frequency components above B cps. The other cases produce harmonics up to infinity, although above approximately $f = 2B$ the magnitude of these harmonics is insignificant.

In order to extract the dc voltage from the detector with any accuracy, it is necessary that the cutoff frequency of the smoothing filter be much less than B. In practice, this means that RC filters must be employed, as suitable inductances would prove far too bulky. In this paper, a simple single-stage RC filter is assumed. Then, the rms ripple error, normalized against $\overline{V}_0$, at the output of the filter of time-constant T_c, is given by

$$r = \sqrt{\frac{1}{(\overline{V}_0)^2}\int_0^\infty \frac{P_0(f)df}{1 + 4\pi^2 f^2 T_c^2}}\,. \tag{43}$$

Since we must choose $T_c \gg (1/B)$, we can replace $P_0(f)$ by $P_0(0)$, and bring it outside the integral. Table IV tabulates the value of r for Cases I, II, and IV.

It is obvious from Table IV that smoothing the detected output (square-law) of a rectangular filter has considerably more rms ripple than the other two filters considered, for the same bandwidth and smoothing time-constant. For the practical filters there is only a minor degradation over using the simplest filter (Case I). This is an important result, since we are striving to keep T_c as small as possible (for reasons that will be discussed below), and the resolving filter as simple as possible.

TABLE IV

Case (as classified in Table I)	Smoothing Filter	r	Ratio
IV	Rectangular Filter	$\frac{1}{\sqrt{2BT_c}}$	1
I	Single-Tuned	$\frac{1}{\sqrt{6.3BT_c}}$	0.55
II	Dual single-tuned (isolated)	$\frac{1}{\sqrt{4.00BT_c}}$	0.71

USE OF A LINEAR DETECTOR

A study of (33), (36), and (39) shows that for each type of resolving filter chosen:

$$\overline{V}_0 = (\text{const}) \cdot P_1 \tag{44}$$

where P_1 can be interpreted as the power density at the center of the filter. If a linear detector were used instead of the square-law one discussed, (44) would be replaced by

$$\overline{V}_0' = (\text{const.})\sqrt{P_1}. \tag{45}$$

This is important to the designer of an airborne spectrum analyzer for several reasons:

1) The dynamic range in db required of a telemeter to transmit $\overline{V}_0$, for the same range of P_1, if (45) is used, is only half that required using (44).
2) As the analyzer sweeps across a peak in the spectral density plot, $\overline{V}_0'$ changes at a slower rate than $\overline{V}_0$, and so the frequencies in the signal presented to the telemeter are lower, and more bandwidth conservation is achieved.
3) The derivation of (44) can be done on the ground by squaring the telemeter output. This means that the size and weight of the airborne device is somewhat reduced.
4) The noise ripple error is reduced significantly.

These points will be discussed in more detail below. They are only listed here to indicate the need for exploring the linear detector.

We can deal with the ripple error of the linear detector very quickly [4]. Suppose the signal of (28) and (29) is applied to a detector obeying the law:

$$V_0(t) = A(t). \tag{46}$$

Then it can be shown that

$$\overline{V_0(t)} = \overline{A(t)} = \overline{V}_0'. \tag{47}$$

$P_0'(f)$, the power spectral density of the noise at the output of the linear detector is given by

$$P_0'(f) = \tfrac{1}{4}P_0(f)$$

where $P_0(f)$ is defined by (32), *et. seq.*

Therefore, to convert the ripple errors (r) of Table IV into the errors obtained using a linear detector, with the same resolving filter bandwidth (B) and smoothing time-constant (T_c), we would reduce each value of r by $\frac{1}{2}$. For example, for Case II, the new ripple error would be

$$r' = \frac{1}{2\sqrt{4.00BT_c}}. \tag{48}$$

If the signal received at the ground station is squared, to obtain P_1, the ripple error in the *output* of the squarer would be as given in Table IV once again. This can be seen by letting $E(t)$ be the noise voltage riding on $\overline{V}_0'$ at the ground station. The normalized rms value of $E(t)$ is r'. The input to the squarer, therefore, is

$$\overline{V}_0'(1 + E(t)).$$

The output from the squarer is

$$[\overline{V}_0']^2(1 + 2E(t)).$$

The normalized rms value of $2E(t)$ is $2r'$. This is precisely the same error that would have been obtained using a square-law detector in the airborne spectrum analyzer.

TRANSIENT CONSIDERATIONS—OUTPUT SMOOTHING CIRCUIT

It would seem from the formulas of Table IV, and from (48), that the time-constant of the output smoothing circuit T_c should be as large as possible. There is, however, a limitation on the size of T_c that can be used. This limitation is imposed by the rate with which a spectral peak is being scanned by the analyzer.

As the peak is scanned, the dc average output $\overline{V}_0$ (using a square-law detector) or $\overline{V}_0'$ (using a linear detector) rises and falls with the peak. The smoothing circuit must pass this transient. For the sake of analysis, let us suppose the spectral peak under study is given by (16). As the spectrum is swept, the transient applied to the output smoothing circuit will have a Gaussian shape. For a square-law output, the transient will have the form

$$V = V_m e^{-(qt - f_n/m)^2}. \tag{49}$$

Our objective is to determine the increase in the width of this transient at its 3-db points as it passes through the smoothing circuit. This can be done by following the method developed by Huggins [6]. We note the similarity of form of the convolution integral, when a transient of (49) is applied to an RC smoothing circuit, to that of the probability integral of the sum of two independent variables. Therefore, we represent 1) the input transient (49), and 2) the impulse response of the RC network, as two independent probability distributions of time. The variance about the mean of the impulse response is T_c^2. Therefore, the variance about the mean of the output of the smoothing circuit is given by

$$m_0^2 = m^2 + T_c^2 q^2. \tag{50}$$

Assuming

$$T_c < m, \tag{51}$$

$$m_0 = m\left[1 + \frac{T_c^2 q^2}{2m^2}\right]. \tag{52}$$

Using (18), we can write the normalized increase in bandwidth as

$$r_d = \frac{m_0 - m}{m} = 2k_0\left(\frac{T_c}{T}\right)^2\left(\frac{f_b}{B_m}\right)^2. \tag{53}$$

For a linear detector, (49) is replaced by

$$V' = V_m{}' \, e^{-(qt-f_n/\sqrt{2}m)^2} \tag{54}$$

and r_d is replaced by

$$r_d{}' = k_0\left(\frac{T_c}{T}\right)^2 \left(\frac{f_b}{B_m}\right)^2. \tag{55}$$

TELEMETRY CONSIDERATIONS

An important part of the design of an airborne spectrum analyzer system is to make sure that the output of the analyzer is compatible with the telemetry scheme. Let us consider a spectral peak as represented by (49). To reproduce this spectral peak at the ground station of a time-multiplex system, we need at least three samples between the $V_m/2$ points; *i.e.*, if s is the sampling rate (per second), we must have

$$s \text{ (Sq. Law Detector)} \geq 6\sqrt{k_0}\left(\frac{q}{B_m}\right). \tag{56}$$

Similarly, if a linear detector is used, the spectral peak is represented by (54), and

$$s \text{ (Lin. Detector)} \geq \sqrt{\frac{k_0}{2}} \cdot \frac{6q}{B_m} \cdot \tag{57}$$

Eqs. (56) and (57) can be reinterpreted in terms of bandwidth as follows. (f_t = the telemetry bandwidth required to pass the output of the analyzer):

$$f_t \text{ (Sq. Law Detector)} = \frac{3\sqrt{k_0}}{B_m} \cdot q \tag{58}$$

$$f_t \text{ (Lin. Detector)} = 3\sqrt{\frac{k_0}{2}} \cdot \frac{q}{B_m} \cdot \tag{59}$$

The dynamic range limitations imposed on the analyzer by the telemetry are also worth a brief look. Suppose that the accuracy of the telemetry is such that

$$D = 10 \cdot \log_{10}\left(\frac{\text{maximum signal before overloading}}{\text{minimum useful signal}}\right). \tag{60}$$

The value of D establishes the useful dynamic range of the spectrum analyzer. Unfortunately, the effect of D varies from spectrum to spectrum, and is difficult to evaluate without establishing a specific spectral density plot. However, it is possible to compare the effects of linear and square-law detectors for the same spectrum. Let us assume a white noise signal is being analyzed, and let d equal the variation in power (in db) over which the combined spectrum-analyzer telemeter system gives useful results at the ground station.

Then for the square-law detector,

$$d = D. \tag{61}$$

Let d' = the tolerable variation in power (db) for the linear detector. Then

$$d' = 2d. \tag{62}$$

Eq. (62) is another reason for favoring a linear detector in the airborne unit.

CHOICE OF PARAMETERS

From the above, we can work out a compatible set of basic parameters for any spectrum analyzer telemetry system. There are four main considerations which affect the choice of spectrum analyzer and telemeter parameters:

1) the compatibility, frequency-wise, of the telemeter and the analyzer output [(56) to (59) apply];
2) the choice of T_c small enough to keep the bandwidth error in the smoothing circuit within satisfactory limits [(53) and (55) apply];
3) the choice of B small enough to keep the filter blurring error within satisfactory limits [(26) applies, if we are interested in interpreting the blurring error as a degradation of bandwidth; (14), if as an error in power density]; and
4) the choice of the product $(B \cdot T_c)$ large enough to keep the ripple on the output to a satisfactory level [the formulas of Table IV apply, for a square-law detector; these results can be modified for a linear detector, as illustrated by (48)].

From the above four considerations, the following parameters are chosen to be compatible: a) the telemetry bandwidth f_t or sampling rates, b) the output RC smoothing time-constant T_c of the analyzer, c) the bandwidth of the analyzer B, d) the total frequency band covered by the analyzer f_b, and e) the time for one sweep period T. Other considerations, affecting gain and dynamic range, have also been covered above. However, these are relatively straightforward, compared to 1), 2), 3), and 4) above.

EXAMPLE

An example is perhaps the best way to show how one can try to establish a consistent set of parameters in a systematic manner, for a case II filter.

Let us consider the case where the analyzer has a linear detector only, and where the telemeter is a time-multiplex system. Let us also assume we are interested in the blurring error as a degradation of bandwidth. Let T be the sweep period (in seconds). Then

$$q = \frac{f_b}{T} \cdot \tag{63}$$

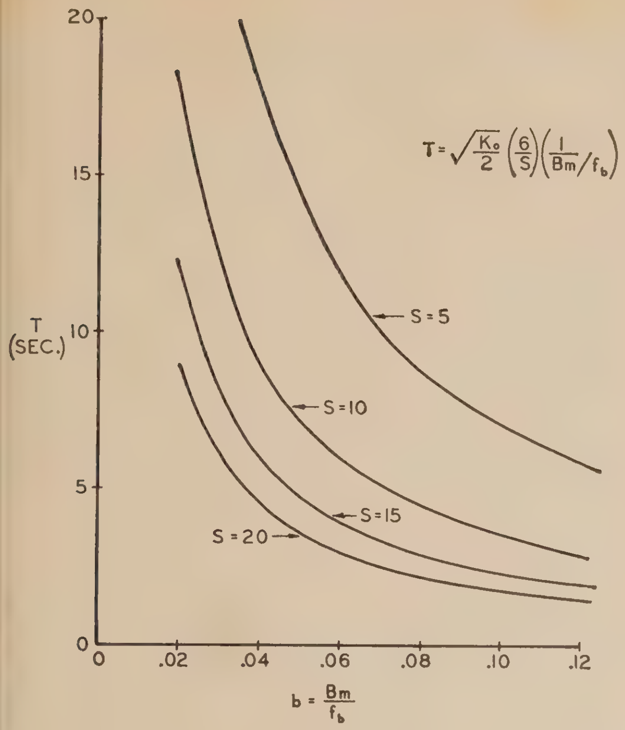

Fig. 1.

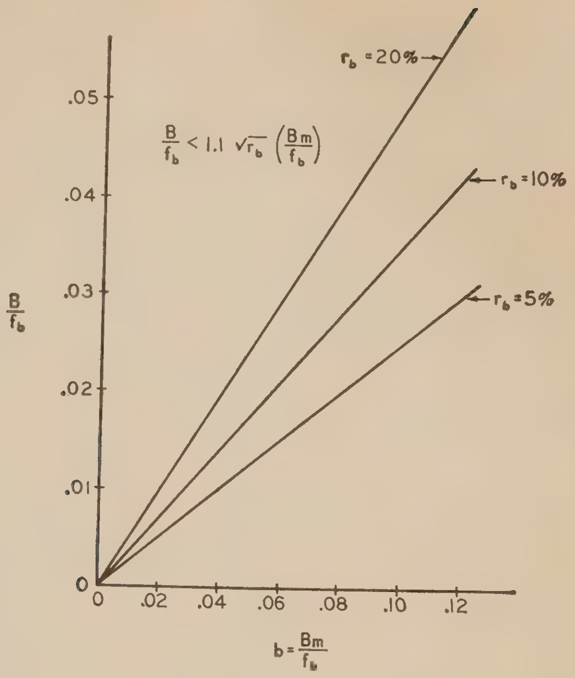

Fig. 3.

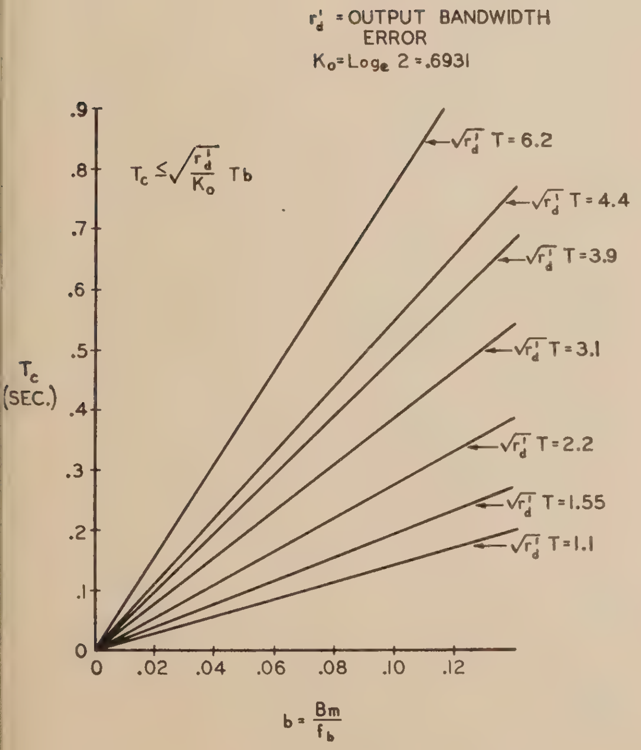

Fig. 2.

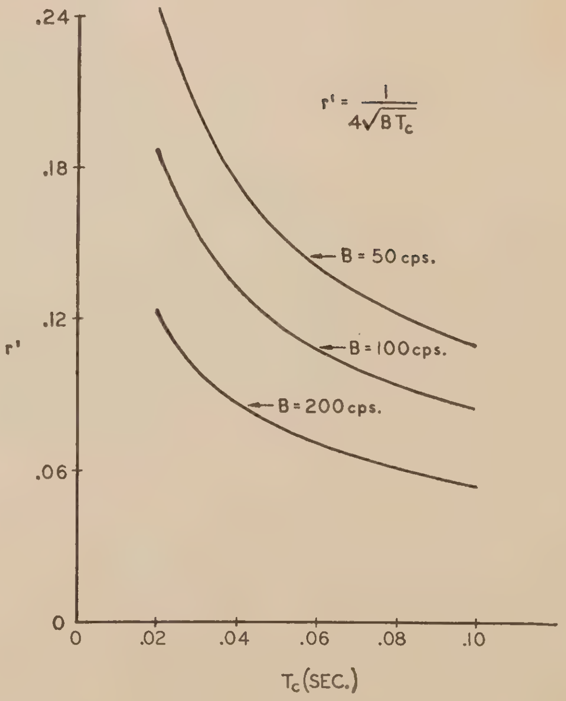

Fig. 4.

and it is possible thereby to eliminate q from all pertinent equations.

It is necessary to establish initially: 1) the maximum ripple error that is tolerable; 2) the maximum output bandwidth error that is tolerable; 3) the maximum blurring error that is tolerable; 4) the sample rate of the time-multiplex system (this is usually well-known; however, the sampling rate can be increased by cross-strapping the multiplexing switch); and 5) the bandwidth of the narrowest spectral peak expected in the random signal under study.

The last, when expressed as a fraction of the total frequency range, is an important quantity. Consequently, let us define it by:

$$b = \frac{B_m}{f_b}. \tag{64}$$

We use the equation for the sample rate, (57), to determine the period of one sweep. This equation is rewritten

$$T \geq \sqrt{\frac{k_0}{2} \cdot \frac{6}{sb}}, \tag{65}$$

and is plotted as Fig. 1.

We can now determine T_c using (55) for the output bandwidth error. This equation is rewritten as

$$T_c \leq \sqrt{k_0^{-1} r_d'} \cdot T \cdot b. \tag{66}$$

Eq. (66) is plotted in Fig. 2.

Next, we use (26) to establish the filter bandwidth B, as follows:

$$\frac{B}{f_b} \leq 1 \cdot 1 \cdot \sqrt{r_b} \cdot b \tag{67}$$

where

$$r_b = \frac{\Delta B_m}{B_m}. \tag{68}$$

Eq. (67) is plotted in Fig. 3.

Finally, we insert the result of (66) and (67) into (48), plotted as Fig. 4. The ripple error so obtained must be less than that desired for a compatible design. If it is not, we must modify our original set of assumptions. The curves given indicate clearly how the various parameters interact, and thus assist in achieving a compromise.

Suppose the frequency band of interest is 2 kc, and we wish an accurate spectral root power density plot for all spectral peaks wider than 200 cps. Suppose also that a 10 sample per second time-multiplex telemeter is to be used. Thus $b=0.10$, $s=10$. From Fig. 1, we see the sweep period T must be at least 3.6 seconds. (This also implies that the random signal under study must remain stationary for at least 3.6; if it is not stationary for 3.6 seconds, Fig. 1 will have to be used to select a larger value of s. Cross-strapping in the telemeter will permit values of $s=20$, 30, 40, etc., to be chosen easily.)

With $T=3.6$ seconds, and $s=10$, there will be a telemetry sample every 55 cps across the frequency band f_b. It seems reasonable to require that the output bandwidth error be $r_d' \leq 0.1$. From Fig. 2, we see we must choose $T_c \leq 0.12$ second. Let us also permit the blurring error to be 10 per cent. From Fig. 3, $B/f_b \leq 0.059$. Thus, $B \leq 80$ cps.

From Fig. 4, the ripple error r' is 10 per cent. If this value is too great to be tolerated, some change in the initial choice of parameters is indicated. s or T must be increased, or r_b and r_d relaxed, or a combination of these changes carried out. For most practical cases, however, a value for r' of 10 per cent is very satisfactory. 10 per cent to 20 per cent is usually an acceptable range of values.

It may be of more use in some situations to use values of B and/or T_c which are smaller than the values chosen, accepting the increases in errors that result. For instance, if the data under study cannot be expected to remain stationary for even 3.6 seconds, a smaller value of T must be chosen. This forces T_c to be smaller than 0.12 second; the larger errors that result in this case are not peculiar to the present analyzer, but are the penalty one must pay with any type of analyzer when the amount of data is reduced.

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The Telemetry and Communication Problem of Re-Entrant Space Vehicles*

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Summary—**The problems associated with propagation of electromagnetic telemetry and communication (and guidance) signals through the densely ionized region (plasma) generated by, and surrounding a hypersonic space vehicle re-entering the earth's atmosphere are reviewed. The nature and extent of the plasma-radio wave interference is explained in terms of the classical treatments which have evolved from ionospheric studies. The limitations of the simple classical models are pointed out in the light of the more complex nature of the hypersonically generated plasma. Methods for overcoming the deleterious influences of the plasma are presented, culminating in presentation of some new approaches to this problem.**

INTRODUCTION

A CONCENTRATED effort by space vehicle researchers, and telemetry and communications engineers, is presently being devoted to establishment of means which will permit reliable and continuous RF telemetry, communication, and guidance information to be exchanged between a hypersonic re-entry vehicle and one or more ground stations. For the scope of this paper, hypersonic vehicles may generally be defined as those whose re-entry flight regime lies in the Mach 10 to Mach 20 region. Their particular configurations, whether they be missile nose cones (Jupiter, Atlas, Thor) [1], [2], aerodynamic lift vehicles (X-15 [2], Dyna Soar [3], [4]), manned re-entry capsules (Mercury) [5], or futuristic rockets and manned satellites, are not of concern here. The common element of interest is their hypervelocity during re-entrant flight phases within an atmosphere. These hypersonic velocities during atmospheric flight result in tremendous aerodynamic heating of the vehicle and its immediate surroundings. Among the many effects of the heating is thermal ionization of the atmosphere surrounding the vehicle. This action results in liberation of free electrons and positive ions in the form of a plasma or sheath surrounding the re-entry vehicle, which serves to interfere with the passage of electromagnetic waves. Such interference is characterized by attenuation, refraction, phase shift, and at times complete absorption or reflection of a passing signal. It is for these reasons that the re-entry telemetry and communication problem has commanded so much attention.

Loss of telemetry signals is commonly experienced during specific portions of the re-entry flight profiles of missile nose cones. This situation is serious in that much important information is lost and continuous tracking of the vehicle becomes difficult. Since the time duration of re-entry is small for re-entrant nose cones, loss of signal during this time can be overcome by storage and recording. However, a high price is paid in the form of weight and instrumentation penalties, and recovery of the nose cone at the termination of its flight is mandatory.

When one considers the re-entry paths of manned vehicles such as returning rockets and satellites of future generations, or the Dyna Soar, Mercury, and advanced X-15 vehicles now in the design stage, the RF signal propagation problem assumes proportions far more serious than is present in nose cone telemetry. This is due to the fact that 1) the periods of time during which propagation of RF signals will be blocked by the plasma sheath surrounding the manned re-entry vehicle will be appreciably longer than for the missile re-entry case—probably of the order of hours rather than fractions of minutes; and 2) these vehicles, being manned and in serious need of continuous exchange of guidance and control information, cannot rely upon storage or delayed relay of that information.

In view of these considerations, the importance of devising means of reliably and continually propagating (or propagating at will) telemetry, communication and guidance information to and from vehicles traveling at hypersonic velocities within the earth's atmosphere is self-evident.

In order to arrive at an understanding of the manner in which reliable and continuous signals may be propagated under these conditions, it is first necessary to become familiar with the nature of the environment induced by hypersonic vehicles, and the mechanisms of interaction between the ions of the plasma and a passing electromagnetic wave. From a consideration of these, it then becomes possible to devise means of removing the interfering obstacles or diminishing their effectiveness, and even to arrive at methods of altering the usual behavior of the interfering mechanisms in order to achieve a cooperative influence which can conceivably result in enhancement of the passing RF wave.

NATURE OF THE INDUCED ENVIRONMENT

A re-entrant vehicle moving at hypersonic velocities within the earth's atmosphere produces a complex flow pattern in the surrounding medium. Macroscopically, the resultant shock wave is characterized by a sharp demarcation or front, behind which air pressure and density increase many times over their normal ambient values. These physical changes are attributable to the vehicle velocity within the medium; the resultant frictional forces induce thermal increases which give rise to

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* Original manuscript received by the IRE, November 23, 1959.

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chemical changes in the medium such as dissociation and ionization.

A qualitative presentation of a typical shock front, its associated layers, and their combined relation to the hypersonic vehicle is depicted in Fig. 1. It is emphasized that the illustration is mainly descriptive and is not meant to depict quantitative geometric relationships. The shock front is the strong line of demarcation separating the ambient atmosphere from the induced environment close to the vehicle. In hypersonic flow past a blunt body, the shock front lies close to the surface, tending to wrap itself about the body [6]. The greatest increases in temperature, pressure, and air density (which we shall conveniently refer to here as the "gas parameters") occur behind the portion of the shock in the vicinity of the vehicle leading edge [7]. The extent of these increases is dependent upon vehicle velocity, configuration, and particular characteristics of the natural environment [8]. For re-entrant and high-velocity vehicles such as X-15 or Dyna Soar, gas parameter increases of one or two orders of magnitude over normal values are to be expected [9]. A more detailed presentation of these variations is presented in Fig. 2.

The region behind the shock front is termed the shock layer. That portion of the layer immediately adjacent to the vehicle leading edge is referred to as the stagnation region. Here the gas flow is subsonic and temperature, pressure, and density reach their maximum values. Further aft, gas expansion occurs, the flow becomes supersonic, and the gas parameters decrease. The boundary layer is that viscous region through which heat transfer and skin friction occur. On a slender after-body, this layer tends to be thicker at hypersonic speeds than at low speeds. It interacts with the external flow, and this gives rise to an induced pressure with a negative gradient which thins the boundary layer somewhat [10].

The chemical constitution of the atmosphere in the various flow and layer regions of the plasma sheath serves to affect strongly the behavior of electromagnetic signals propagated through them. This comes about because conversion of flow energy into internal energy of the surrounding air results in dissociation and ionization of the gas molecules. Notable among the dissociation products is the formation of nitric oxide which is easily ionized, thus contributing to the formation of large numbers of ions and free electrons [11].

It is this concentration of ionized particles about the hypersonic vehicle which works to interfere with the passage of electromagnetic RF waves to and from the vehicle. This interference is characterized by attenuation, refraction, and possible reflection of the wave during its travel through the region.

The large temperature gradients existing within the boundary layer region bring about diffusion and recombination on the vehicle surface of free atoms from the hot gases surrounding the vehicle. In this process the constituents of the plasma give up their heat of dissociation, thereby transferring heat from the gaseous surroundings to the vehicle surface. This serves to alleviate by a small but insufficient amount some of the interference phenomena mentioned previously.

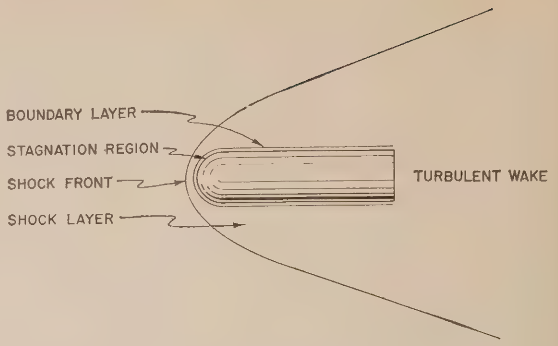


Fig. 1—Geometry of environment induced by a blunt hypersonic body.

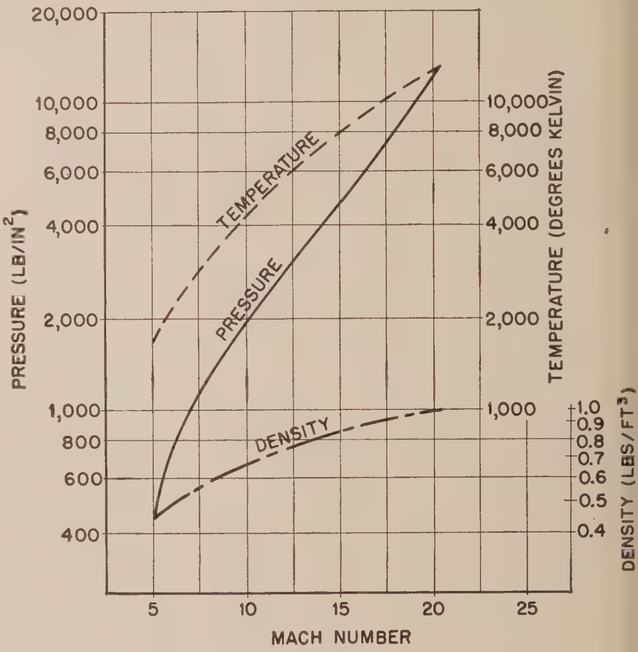


Fig. 2—Induced environment characteristics as a function of Mach number.

It is thus seen that the environment induced by a hypersonic vehicle is most complex, and the chemical and physical processes which induce and sustain it in its state of dynamic flux also act to alter the behavior of co-existing mechanisms such as heat transfer, vehicle erosion, electromagnetic radiation, etc. As will be seen later, the complexity of these interrelations and the nature of the combined mechanisms make the accurate expression and analyses of these phenomena a formidable problem.

INTERACTION OF INDUCED ENVIRONMENT WITH ELECTROMAGNETIC RADIATION

The interactions of electrons and waves, and the resultant effects upon electromagnetic propagation have been ascertained by various investigators. Baker and Rice [12], Hartree [13], Lorentz [14] and others have derived relations governing the dependence of permittivity and refractive index of an ionized medium upon its electron density and frequency of the passing wave. Appleton [15] has formulated the dependence of the above relations upon externally imposed magnetic fields and has accounted for the loss effects due to the presence of dissipative factors in the medium. Similarly, expressions for intrinsic impedance, reflectivity, and conductivity have been formulated by Everhard and Brown [16], Eccles [17], Baker and Rice [12], and Margenau [18]. These relations have, in turn, yielded expressions for the propagation constant and its dependence upon wave frequency, plasma frequency, and collision frequency. The limitations of Margenau's work to field strengths of low values have been removed and his work extended to some extent by Everhart and Brown [16], and Cahn [19], resulting in relatively simple expressions for conductivity and propagation constant over a wide range of values of field strength, wave frequency, and air pressure.

Approximate Formulations

It is to be noted that much of the work referred to above is based upon investigation of the ionosphere. A great deal of this is predicated on simple classical theory which considers the behavior of average, individual electrons while neglecting their over-all velocity distribution. Generally, though not always, a plane wave is considered and the ionized medium it traverses is assumed to be isotropic, homogenous, constant, and linear. For specific application to ionospheric studies, a slowly-varying stratified distribution of electron density in a uniform magnetic field is often assumed. Further common assumptions consider the energy added to the electrons by the passing electromagnetic wave as small compared to their kinetic energy, effects of electron collisions are neglected, and the associated positive ions of the plasma are assumed immobile [20]. These assumptions generally do not reflect accurately the conditions accompanying propagation of RF signals to and from a vehicle surrounded by a hypersonically-generated ionized sheath, but they have been necessary in order to make possible the mathematical description of even the simpler phenomena and to evolve associated quantitative formulas. Yet, if the results are considered in proper context with full appreciation of the limitations involved, they can be of value in understanding some of the basic phenomena underlying wave propagation through hypersonically generated plasmas.

In order to arrive at such an understanding, it is instructive to consider from a qualitative aspect the electric field of an electromagnetic wave incident upon an ionized region and exerting a force upon the electrons of that region. (The positive ions, being many times heavier than the electrons, are assumed immobile; hence only the electrons are effective in interacting with the electromagnetic wave [21].) Some of the excited electrons collide with heavier gas molecules, giving up part of their kinetic energy to the molecules, and re-radiating the remainder in the form of a distorted radio wave; the result is an absorption of energy from the incident wave. Discounting these occasional collisions with heavier ions and the influence on the excited electrons of either the earth's natural magnetic field or of an artificially imposed magnetic field, the direction of the induced electron vibration parallels the electric field vector of the radio wave. The vibrating electrons behave as miniature parasitic antennas, alternately absorbing and re-radiating the radio-wave energy incident upon the ionized gas. The net effect of this mechanism is an alteration of the phase velocity of the wave, a change in the intrinsic impedance of the medium, and a refractive action wherein the wave path is bent away from the regions of high electron density toward regions of lower electron density [22]. Consider the refractive index; using the model described above, it can be expressed simply as [12]

$$n = \sqrt{1 - \frac{Ne^2}{\epsilon_0 m \omega^2}}, \tag{1}$$

where

e = electron charge in coulombs,
m = electron mass in kilograms,
ω = frequency of wave propagation in radians/second $= 2\pi f$,
N = number of electrons/meter^3, and
ϵ_0 = permittivity of free space.

This equation is derived from the assumption that the average time between collisions of an electron with other particles is appreciably greater than the period of the exciting or impinging wave, *i.e.*, collision frequency ν is less than wave frequency f.

It should be noted in (1) that $n=0$ when $Ne^2/\epsilon_0 m = \omega^2$. This particular value of ω is termed the critical or plasma frequency ω_{cr} and is defined precisely as that propagation frequency at which the refractive index is zero in the absence of a magnetic field. For $\omega > \omega_{cr}$, n is real, and unrestricted wave propagation is present; for $\omega < \omega_{cr}$, n is imaginary and only evanescent waves exist. For $\omega = \omega_{cr}$, complete reflection occurs, and there is no wave propagation through the medium. Thus, by considering the simple model of interacting electric wave vectors and plasma electrons, we have arrived at the concept of critical or plasma frequency, and have gained a knowledge of frequency limits of propagation and their dependence on ionization density.

By using similar techniques based upon simple models, relations for wave attenuation, phase shift, plasma conductivity, intrinsic impedance, and reflectivity have been derived by a number of investigators [12]–[19]. These expressions have been compiled in part by DeVale, *et al.* [23], and Sisco and Fiskin [24]; these are combined below in a common set of units for convenient reference.

attenuation constant $$\alpha = \omega\sqrt{\frac{\mu\epsilon}{2}\left(\sqrt{1+\frac{\sigma^2}{\omega^2\epsilon^2}}-1\right)} \tag{2a}$$

phase shift constant $$\beta = \omega\sqrt{\frac{\mu\epsilon}{2}\left(\sqrt{1+\frac{\sigma^2}{\omega^2\epsilon^2}}+1\right)} \tag{2b}$$

plasma frequency $$\omega_{cr} = \sqrt{\frac{Ne^2}{\epsilon_0 m}} \tag{2c}$$

conductivity $$\sigma = \epsilon_0\frac{\omega_{cr}{}^2\nu}{(\nu^2+\omega^2)} = \frac{Ne^2\nu}{m(\nu^2+\omega^2)} \tag{2d}$$

permittivity $$\epsilon = \epsilon_0\left(1-\frac{\omega_{cr}{}^2}{(\nu^2+\omega^2)}\right) = \epsilon_0\left(1-\frac{Ne^2}{\epsilon_0 m(\nu^2+\omega^2)}\right) = \epsilon_0 - \sigma/\nu$$

reflection coefficient $$\rho = \frac{\eta-\eta_0}{\eta+\eta_0}$$

intrinsic impedance $$\eta = \sqrt{\frac{\mu}{\epsilon\left(1+\frac{\sigma}{i\omega\epsilon}\right)}}$$

index of refraction $$n = \sqrt{1-\frac{Ne^2}{\epsilon_0 m\omega^2}}$$

relative permittivity $$\epsilon_r = \epsilon/\epsilon_0 = 1 - \frac{1}{(\nu/\omega_{cr})^2+(\omega/\omega_{cr})^2}$$

relative permeability $$\mu_r = \mu/\mu_0 = 1$$

gyromagnetic frequency $$f_h = \frac{e\mu_0 H}{2\pi m}.$$

In the above expressions:

e = electron charge in coulombs,
m = electron mass in kilograms,
N = electron density (electrons/meter^3),
ϵ = permittivity of plasma,
ϵ_0 = permittivity of free space,
μ = permeability of plasma,
μ_0 = permeability of free space,
ϵ_r = relative permittivity,
n = refractive index,
η = characteristic impedance,
γ = propagation constant = $\alpha + j\beta$,
η_0 = intrinsic impedance of free space,
ν = collision frequency,
H = magnetic field (ampere turns/meter).

In order to demonstrate the nature of the dependence of some of these parameters on electron density (and, therefore, on vehicle velocity and plasma frequency), the attenuation and phase shift have been plotted in Figs. 3 and 4 over a wide range of propagation frequencies. Note in Fig. 3 the large attenuation which accompanies high electron densities (plasma frequencies), and the rapidity with which attenuation drops off as wave frequency approaches plasma frequency. It is interesting to note that the frequency range of greatest attenuation (100–1000 mc) in Fig. 3 corresponds to a region approximating phase shifts which are comparable to free space values (see Fig. 4). In other words, if one desires to obtain normal phase shifts in propagating through a plasma, one must then contend with high

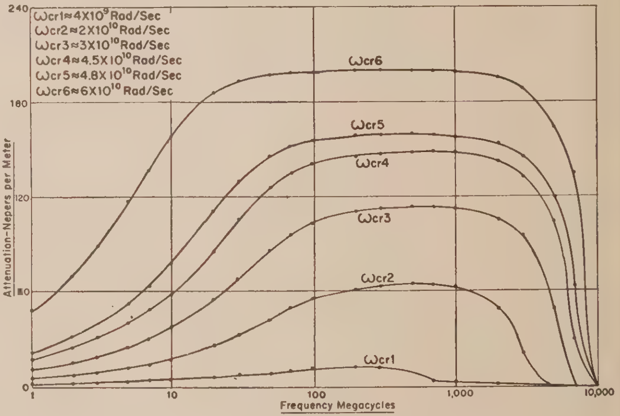


Fig. 3—Attenuation vs frequency for various plasma frequencies (electron densities).

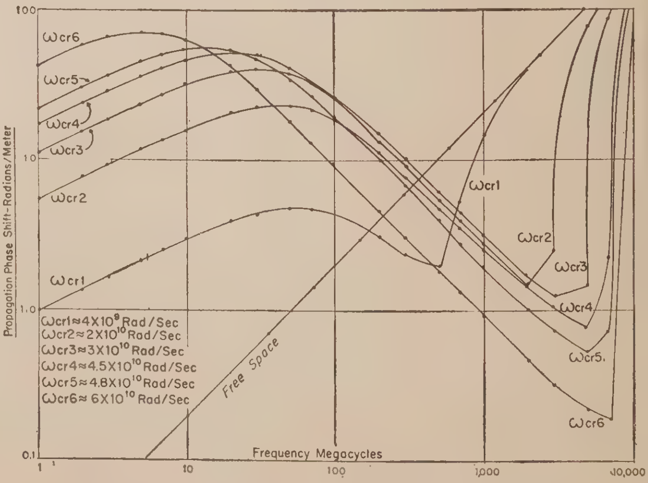


Fig. 4—Propagation phase shift vs wave frequency for various ionization levels (plasma frequencies and electron densities).

wave attenuation. Note also in Fig. 4 that as wave frequency approaches plasma frequency, the phase constant undergoes violent variations. This points up the desirability of utilizing the lowest of wave frequencies for propagation; as shall be noted later, however, low wave frequencies introduce unique problem areas.

Since wave attenuation and phase shift are such important parameters in radio communications and telemetry, let us now consider the influence of a superimposed magnetic field upon the attenuation and phase of a wave passing through a plasma. Again, this can be explained in terms of our oscillatory electron and wave vector model. It has been found that at high wave propagation frequencies the velocity of vibration of the excited plasma electrons is practically unaffected by application of a mild external field, *i.e.*, the excited vibrating electrons are placed into paths which are only slightly elliptical, deviating but little from the linear motion described earlier. Accordingly, the effective conductivity of the plasma is practically equivalent to that of the zero-magnetic field case of (2d). As the wave frequency is lowered, the vibrational velocity of the excited electrons increases and their paths become elliptical and then circular [25]. At a frequency value expressible as [26]

$$\omega_h = \frac{e\mu_0 H}{m} = 2\pi f_h, \tag{3}$$

the electron vibrational velocity is greatly increased, and the conductivity of the plasma becomes correspondingly great. This, of course, is manifested by an increase in wave attenuation. The particular frequency f_h at which these phenomena are observed is termed the gyromagnetic frequency of the medium. At frequencies greatly less than the gyromagnetic frequency, the applied magnetic field serves to decrease the electron vibrational velocity well below the value which would be present were the magnetic field absent. Thus, electron collisions and, consequently, plasma conductivity is decreased, resulting in decreased attenuation of passing electromagnetic waves. This behavior has been confirmed for high-frequency radio waves propagating through the earth's atmosphere with the earth's magnetic field acting as the influencing magnetomotive force. The earth's magnetic field has a value of approximately $\frac{1}{2}$ gauss; using this value in (3) gives a value of 1.4 mc for the electron gyromagnetic frequency. This corresponds to a wave propagation wavelength of 214 meters. Nichols and Schelling [25] have found that marked wave attenuation of propagated waves occurs at precisely this frequency, with a decrease of attenuation taking place at longer and shorter wavelengths. This behavior is also recorded by Baker and Rice [12].

In view of this influence of the earth's natural magnetic field upon wave attenuation and phase shift, one is led to conjecture the effects of artificially imposed magnetic fields on wave propagation. This point is considered in the following section in which the possibility of this approach is considered.

An indication of the dependence of plasma frequency upon electron density is presented in Fig. 5. Calculations have shown that the electron densities generated by a hypersonic aerodynamic vehicle lie close to the curve of Fig. 5 if the axis of abscissas is calibrated in Mach number (see top of Fig. 5). This near-coincidence of curves remains valid up to about Mach 14 or 15, after which other processes set in, which cause the vehicle velocity vs plasma frequency relationship to deviate from the electron density vs plasma frequency curve of Fig. 5. This frequency-velocity-electron density relationship means that RF telemetry or communication can be carried on to and from the re-entering hypersonic vehicle only at frequencies equal to or greater than the critical or plasma frequency corresponding to the particular re-entry velocity. Thus, at Mach 10, the frequency must be above 200 or 300 mc; at Mach 17 the minimum usable frequency is 5000 mc, etc. Frequencies immediately below the plasma frequency will not penetrate the ionized sheath surrounding the re-entry vehicle, and hence are unsuitable for establishment of telemetry or communications. This is particularly disconcerting in present day telemetry and communication practice, due to the extremely heavy equipment investment in the VHF-UHF range. In view of this, the importance of devising means of transmittal through the hypersonically-generated plasma of VHF-UHF radio waves is easily appreciated.

Alternate approaches utilizing microwave frequencies

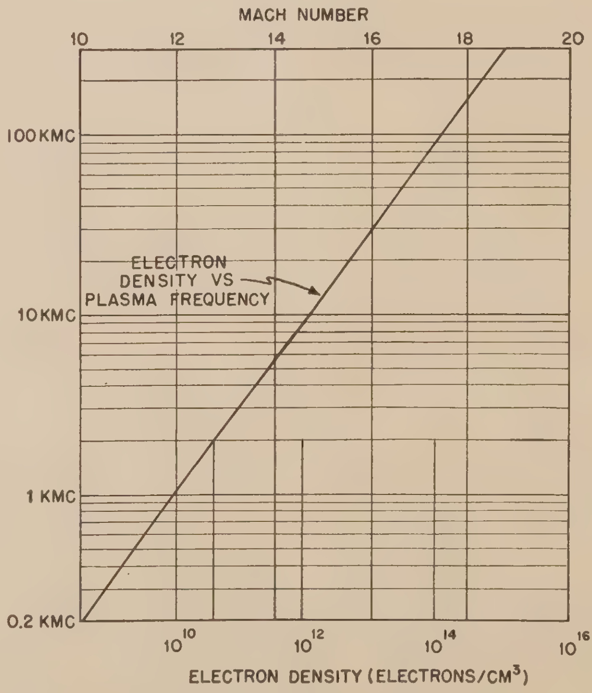


Fig. 5—Plasma frequency as a function of electron density and Mach number.

on the one hand or very low radio frequencies on the other, though offering some solutions to the propagation problem, introduce their own peculiar complications. These will be discussed below.

Exact Formulations

The task of devising, analyzing, and evaluating the exact mechanisms of electromagnetic wave and plasma interaction at the lower radio frequencies is extremely difficult due to the complicated nature of the plasma itself, the proximity of vehicle antennas to the plasma, and the difficulty of reasonably expressing the interactions and relations existing between the two. The dimensions of the shock front and of the various layers constituting the ionic sheath are not constant, but vary with vehicle velocity and environmental conditions—and consequently with temperature and density. The composition of these regions varies also in space and time, thus making untenable the convenient concepts of homogeneity, isotropy, and constancy so effectively used in common wave propagation analyses. Because the antenna is either embedded, in contact with, or very close to the plasma sheath, the effect on the near field radiation components is substantial. As a result the input impedance characteristics are different from the free-space radiation case. Furthermore, since the plasma sheath thickness is generally small, or comparable to the antenna dimensions, the fields arriving at its outer boundary do not constitute a plane wave; thus the conventional coefficients of transition, *viz.*, reflection and transmission, do not apply, and the over-all analysis is accordingly made more complex.

Determination of the nature of the plasma itself is complicated by the gas behavior at the high temperatures associated with hypersonic velocities. Under these conditions, energy is consumed in exciting the translational, rotational, and vibrational degrees of freedom of the gas molecules, the energy levels of atomic electrons are increased, and outer orbital electrons are liberated from their atoms and made available to react with incident electromagnetic waves. Also erosion, sputtering, and mass ablation from the vehicle surface introduce impurities into the ionic cloud which further complicate the description of wave and particle interaction.

Because of the complexity of these processes, and the present lack of knowledge concerning their over-all qualitative and quantitative nature, exact analyses and formulations are prohibitively difficult. Some excellent work has been started in this regard [24], [27], [28], but much of it deals only with specific (and sometimes isolated) aspects of the over-all problem. The truly comprehensive approach must take into account the specific nature and behavior of the medium in all of its varied interactions with electromagnetic waves. Since much of this knowledge cannot be adequately arrived at on purely theoretical grounds, recourse must be had to experimental processes such as those described by Hertzberg [11] and Yoler [29]. In this manner, the validity or falsity of certain assumptions employed in the theory can be ascertained with resulting mutual benefit to both disciplines. It is expected that this would be an iterative process resulting in specific mathematical models which are continually readjusted, appraised, and formulated in the light of confirming and guiding experimentation. When the theoretical formulations have progressed to the point where the potentialities of laboratory experimentation are exhausted, the process would then be advanced to actual flight testing in vehicles which are even now in the design and advanced development stage [30], [31]. It is emphasized that in attacking a problem of this complexity, isolated approaches on specific phases, be they experimental or theoretical, are insufficient to produce the breakthrough that is demanded. This can be realized only by a unified and integrated concentration of many disciplines brought to bear simultaneously upon the common objective.

New Approaches for Achieving Transmission of UHF-VHF Signals Through Hypersonically Generated Plasmas

It has been stated earlier that transmission of RF signals through the hypersonically generated plasma can be effected by utilizing extremely high frequencies such as microwaves (and even optical frequencies) [32] or, on the other hand, by using low radio frequencies such as VLF. The attenuation and phase shift curves of Figs. 3 and 4 and the discussions accompanying them indicate the advantages of using frequencies at either end of the RF band. Let us now look at these viewpoints more closely. Consider first the utilization of microwave or higher frequencies. First, it is evident that since most of the telemetry, guidance, and communication equipment presently in use is designed mainly for the VHF-UHF band, an extensive investment in equipment and technique development would be required before these higher frequencies could be effectively employed for the extensive uses mentioned above. Secondly, interaction of microwaves with the dipole moments of the particles formed in the hypersonically generated plasma are to be expected under certain conditions. Atmospheric attenuation processes are also present which superimpose on the usual inverse square range dependence an exponential decrease of wave intensity with distance from the source [33]. In view of these characteristics, the advantages of microwaves over lower frequencies are few for the applications considered here.

Now consider the VLF range. Again, since most of the present-day telemetry and airborne communication equipment is not in this band, the major drawback of extensive equipment development in the VLF range is present. Design of such equipment for airborne use is fraught with many problems because of the long wavelengths and correspondingly large size of the associated components which are required. As a result, heavy penalties are to be paid in terms of weight, size, and power consumption if VLF equipment is considered for airborne application. Further, since the ionosphere is essentially reflective to VLF waves, propagation problems are to be expected if portions of the vehicle flight profile lie within the various ionospheric layers of the earth [34]. Thus, as a greater number of details concerning the nature and equipment of VLF, microwave, and optical frequencies are considered, the more evident becomes their unsuitability for solving (except perhaps as a last resort) the problem at hand.

In view of this, the desirability of propagating telemetry, guidance, and communication signals within the established VHF-UHF bands is evident. Since, however, the plasma is essentially opaque to these frequencies, it becomes necessary to devise new approaches whereby the transmissivity of the plasma may be increased for signals in these bands. It appears that most such approaches can be grouped into two categories: 1) those which depend upon removal of the ionic sheath or in some way altering its deleterious influence on RF waves, and 2) those which seek to advantageously utilize the presence of the sheath by introducing modifications which will permit the sheath to actually enhance RF propagation. The former are conveniently referred to as recombination and cooling techniques; the latter as electric and magnetic interaction methods. These will now be considered in the above-named order.

Recombination and Cooling Techniques

The techniques of this first category seek to remove the electron influence on electromagnetic fields by removing the electrons themselves through such processes as diffusion, chemical interaction, and application of static electric and magnetic fields to the ionized regions. Two such suggested approaches depend on local cooling of the vehicle and chemical neutralization of the plasma [35], [36]. These methods are of interest not only to the electrical engineer concerned with propagation of RF signals through the sheath, but also to the aerodynamicist concerned with the heat absorption problem of the re-entrant vehicle. The referenced local cooling methods are based on separation of the laminar air flow over a hypersonic vehicle. This is induced by means of a "spike" in the vehicle's nose and "razor blade" extensions of all leading edge surfaces. The resulting detached air flow [37] lowers the equilibrium temperatures of the vehicle surfaces, and injection of a gas into the resulting separation space can theoretically reduce the heat transfer to the body. Such a technique serves to decrease the electrical conductivity of the ionic sheath (and therefore increases the transmissivity of radio waves) by eliminating the contamination products of ablation and vehicle surface sputtering. The problem of the dense electron concentration within the plasma itself still remains, however.

Cooling of the region surrounding a hypersonic body may be effected by specific endothermic chemical reactions such as, for example, the formation of acetylene and monatomic hydrogen from diatomic hydrogen with a total heat absorption of approximately 100 calories per gram molecule [36]. The problem here lies in the development of stable compounds which are highly endothermic in order to reduce the quantity of chemicals which must be transported in the vehicle and circulated over its surfaces. A related process for decreasing ion concentration within the plasma depends upon the mechanism of diffusion, *i.e.*, the movement of ions solely on the basis of their thermal motion. The comparative thinness of the boundary layer surrounding a hypersonic vehicle, and the large temperature differences existing on either side of it, indicate the presence of large thermal gradients within that layer. These thermal differences are instrumental in attracting atoms of the hot gases of the shock layer to the surface of the vehicle where they can recombine to give up their heat of dissociation. Increase of this thermal gradient by cooling of the vehicle surface can conceivably result in larger scale diffusion processes and consequently greater degrees of deionization. It is in this respect that the dissociation mechanism is related to the above-mentioned cooling processes.

Suggestions dealing with chemical alteration of the plasma seek to inject substances into the plasma which have an affinity for electrons. Thus the deleterious interactions of the electrons with RF waves are removed by attaching the electrons to heavier ions which are less mobile than electrons and therefore less capable of interacting with the passing waves. Presumably, such substances would be those whose outer atomic shells are short of completion by one or two electrons and would therefore readily accept free electrons. Thus, the outer, or L, shell of fluorine is composed of seven electrons—just one short of the full complement of eight allowable L electrons. Presumably, then, fluorine would be a good acceptor of electrons. Similarly, oxygen, which lacks two electrons in its outer shell, would also be a good acceptor. There evidently exists a wide variety of substances which are well-suited to act as electron acceptors. It remains to determine the nature of their interactions at the high temperatures involved in a hypersonically generated plasma and the nature of the ions and compounds which are formed in these interactions. The accomplishment of this must depend in great part on experimental measurements in high temperature facilities such as shock tubes and plasma torches.

In a similar vein, related suggestions have been put forth concerning use of artificially generated magnetic fields upon the plasma in order to decrease RF attenuation and generally improve wave transmission through ionized regions. The prevalent mechanism here has been mentioned in the previous section. It was stated there that at frequencies much lower than the gyromagnetic frequency, applied magnetic fields will act to decrease the electron vibrational velocity far below the value with which it would oscillate in the absence of the fields. This is manifested as a decrease in effective plasma conductivity and, consequently, a decrease in the wave attenuation properties of the medium. From (4) gyromagnetic frequency may be expressed as $f_h=3.52\times10^4$ H, where H represents the applied magnetic field in ampere turns per meter. Assume that a field of 500 gauss could be generated through a particular region of the plasma. In this case, f_h is approximately equal to 1400 mc. Radio frequencies in the VHF communication and telemetry band lie well below this value. Thus, such frequencies are capable of decreasing the plasma conductivity as mentioned earlier and are potentially capable of creating a transmission window through the hypersonically generated plasma. It is recognized that generation of large magnitude magnetic fields in an airborne vehicle and through an associated plasma of even moderate physical dimensions is extraordinarily difficult; hence if such a technique is not to remain merely an academic curiosity a great deal of effort must be devoted toward practical means of establishing and maintaining such a field.

Electric and Magnetic Interaction

Among the methods of this second category which seek to utilize the plasma sheath for enhancement of RF transmission, two stand out as offering some promise [38]. These describe conditions which influence the transmission of electromagnetic radiation through ionized regions. The first of these, based on the magnetoionic theory [15], [39], is concerned with parameters which either permit or restrict transmission. The second, which has its foundation in the electromagnetoionic theory [40], postulates actual wave amplification during propagation through ionized regions when certain conditions are fulfilled.

Consider first the magnetoionic postulates. The propagation of a plane electromagnetic wave in a homogenous ionized gas depends on the electron density N, the mean frequency ν of collision of an electron with a molecule or ion, the electromagnetic wave frequency f, the steady magnetic field H, and the angle between H and the direction of propagation. The magnetic field can be expressed in terms of the gyromagnetic frequency f_h of a free electron; electron density is commonly expressed in terms of the plasma frequency f_{cr}. In describing the phenomena of interest, it is common to utilize three parameters which are expressed as follows:

$x = (f_{cr}/f)^2$ which is proportional to N,

$y = f_h/f$ which is proportional to H,

$z = \nu/2\pi f$ which is proportional to ν.

In the absence of magnetic fields, and for small electron collision frequency, the refractive index of the medium may be expressed as

$$n^2 = 1 - x.$$

This is recognized as (1). Normal propagation exists when x is less than unity. When $x=1$, the refractive index becomes zero, which indicates a condition of complete wave reflection; for $x>1$, the refractive index becomes imaginary. Physically, this is indicative of extreme attenuation of the wave within the medium, a condition analogous to the phenomenon of attenuation in a waveguide beyond cutoff. For $x<1$, propagation within the medium is permissible, subject to attenuation due to collision of excited electrons with ions. This attenuation is $\alpha=\nu x/nc$ where c is the velocity of light. As x is increased from its less than unity value, which is caused by increasing the number of electrons in the region, ν increases and n decreases; thus the refractive index rapidly approaches zero. When a steady magnetic field is superimposed upon the ionized region, the electromagnetic ray traversing the region divides into two modes, the so-called ordinary and extraordinary rays. (Piddington [42] has shown that the magnetoionic medium is really quadruply refracting and not merely doubly refracting. This conclusion is reached when heavy-ion motions are taken into account in the analysis—a fact which we find unnecessary to consider in this paper.) Depending upon the magnitude and orientation of the magnetic field, the emerging waves are elliptically, circularly, or linearly polarized. In considering the passage of electromagnetic radiation through the ionized region, superposition of a static magnetic field of varying intensity throughout the region can lead to conditions conducive to escape of the wave [26]. Fig. 6 shows a plot of x (proportional to electron density) vs y (proportional to steady magnetic field). The points A, B, and C represent the values of x and y at corresponding points in the ionized region. An electromagnetic wave passing out of the plasma is represented by the ABC path approaching the origin of the xy-coordinate system. When the wave emerges from the plasma, the point O of Fig. 6 is reached. Thus, if x and y (*i.e.*, electron density and magnetic field intensity) can be made to decrease in proper magnitude as the wave emerges to the edge of the ionized region, then escape of the wave is possible. Curves II and III denote other possible modes of electron and magnetic field decay.

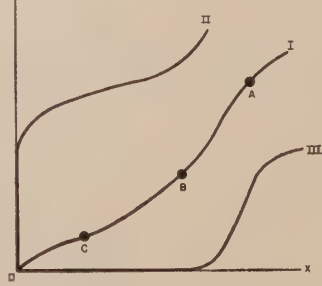


Fig. 6—Representative modes of decay of electron density and magnetic field (after Pawsey and Bracewell). $x \propto$ electron density; $y \propto$ magnetic field intensity.

A further analysis of these magnetoionic mechanisms indicates that definite pass and stop regions exist in a plasma which has a magnetic field superimposed on it. These regions are separated by surfaces expressible as zeros or infinities of the refractive index. Zeros occur at $x=1\pm y$ for longitudinal propagation (direction of wave travel parallel to magnetic field) and for $x=1$ and $x=1\pm y$ for transverse propagation (direction of wave travel perpendicular to magnetic field). Infinities occur for

$$y=\sqrt{\frac{1-x}{1-x\cos^2\theta}}$$

where θ denotes the angle between magnetic field and direction of wave propagation.

The zeros and infinities for the longitudinal case are depicted in Fig. 7 for the ordinary and extraordinary rays; the corresponding stop and pass regions are shown in Fig. 8(a) and 8(b). It is seen that the introduction of a suitable magnetic field, combined with a controlled electron density, permits propagation of waves in certain regions of high electron density which, without magnetic fields, would be stop regions.

It is important to note, however, that the magnetoionic theory is strictly applicable to radio astronomy phenomena. Thus, it is predicated upon conditions involving shallow gradients of electron density and magnetic field. It is doubtful that the electron distribution in hypersonically generated plasmas conforms to this requirement, although it is conceivable that some suitable alteration in electron distribution could be effected. If this can be accomplished together with generation of suitable magnetic fields, it is probable that the magnetoionic approach may offer some promise in solving the re-entry telemetry and communication problem.

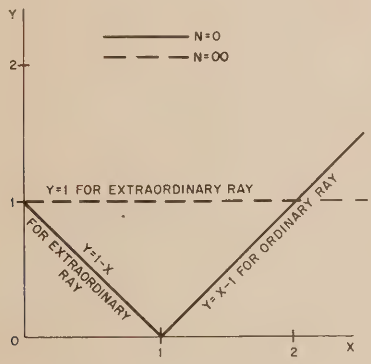
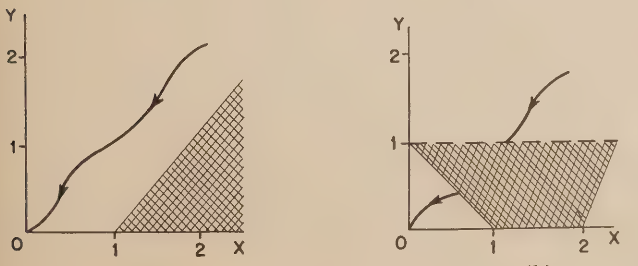


Fig. 7—Zeroes and infinities of refractive index for the magneto-ionic modes (after Pawsey and Bracewell). $x \propto$ electron density; $y \propto$ magnetic field intensity.



(a) (b)

Fig. 8—Stop (shaded) and pass regions for the magneto-ionic modes (after Pawsey and Bracewell). (a) Ordinary ray. (b) Extraordinary ray. $x \propto$ electron density; $y \propto$ magnetic field intensity.

Consider now the electromagnetoionic theory which postulates electromagnetic wave amplification during propagation through ionized regions when certain conditions are fulfilled. This theory is a generalized description of the behavior of plane waves in an ionized medium pervaded by static magnetic and electric fields; as a limiting case it includes the well-known magnetoionic theory, and its application is subject to the same restrictions governing the magnetoionic theory. It is developed from the following laws of physics:

1) Maxwell's laws of the electromagnetic field.
2) Conservation of electrons and positive ions.
3) Maxwell's laws of the transfer of momentum in mixtures of different kinds of particles which are subject to fields of force.

These laws can be expressed completely by a set of six equations relating electric and magnetic fields, scalar and vector potentials, electron drift velocity, and induced perturbation effects. These are reducible to a set of three simultaneous equations whose solution yields the equation of dispersion; from this equation, the varying electric and magnetic field vectors are derived.

When the dispersion equation is plotted as a function of wave frequency ω, the resulting curve is found to cut the ω axis at specific points which define the limits of frequency bands within which the refractive index of the medium is purely imaginary. In accordance with magnetoionic theory, these are regions of extreme wave attenuation—essentially stop regions for electromagnetic propagation. Pursuing the matter further, Bailey [40] has shown that when an electron drift velocity exists, the corresponding curve has some branches similar to the ones considered above, but distorted in a skew manner so that they become unsymmetrical about the ω axis. As a result, bands are formed in which the refractive index is not purely imaginary, but a complex number. This indicates that the effect of electron drift creates wave amplification in frequency bands in which otherwise waves cannot be propagated. A further implication of the theory is that no wave amplification is possible when the wave is propagated transversely to both the drift velocity and the applied steady magnetic field. However, when the electron drift and magnetic field have a common direction, wave amplification is increasingly favored by orientation of the direction of propagation toward this common direction.

Once again it must be emphasized that the tenets of this theory, like those of the magnetoionic theory, are based upon radio astronomy phenomena. Hence, prior to their application to problems of electromagnetic transmission through hypersonically-generated plasmas, it is essential to determine the relative magnitude of the effects involved and the scaling relations which may need to be employed in order to achieve workable relations among the various phenomena involved. Thus it is false to assume that these theories can be applied in blanket fashion to the electromagnetic propagation problems outlined in this paper. What is implied, however, is that these theories appear capable of providing the essential analogous elements whereby adjustments and alteration of the physical conditions imposed by plasmas and waves can be effected to produce constructive rather than destructive interference in their mutual interaction.

DISCUSSION

Application of the classical ionospheric treatments of electron-ion-radio wave interactions to the plasma-radio wave interference problem can yield only limited workable results. This is attributable to the fact that the plasma is more complex than the ionosphere, sharply varying, and composed of small regions with relatively sharp boundaries. The theoretical treatment which is required to adequately describe the phenomena involved is extremely complicated, and probably cannot be accomplished without the aid of associated laboratory and free flight experimentation.

Although many of the difficulties associated with RF transmission through plasmas can be removed by use of very low or very high (microwave) radio frequencies, this recourse leads into economic problems due to the heavy equipment investment in the VHF-UHF telemetry and communication bands. Further, the high frequencies in the microwave region are susceptible to their own peculiar interactions with the molecules of the plasma and with the atmosphere itself. The very low frequencies, on the other hand, extract heavy penalties in terms of size and weight of the components which constitute the equipment, and present the added disadvantage of ionospheric reflection—a serious drawback when the re-entry vehicle is above or within the various layers of the ionosphere. This leads to the conclusion that intensive effort should be devoted to establishing means of transmitting VHF-UHF signals through the hypersonically-generated plasma sheath, and that microwaves or very low frequencies should be employed only as a last resort.

Suggested techniques for propagating VHF-UHF signals through the plasma depend upon recombination processes (to remove the plasma electrons and their deleterious influence) or imposition of auxiliary electric and magnetic fields on the electrons and ions (to induce passage and/or amplification of the passing RF wave). Some theoretical difficulties are to be anticipated in applying the latter approach to the present problem because it has its roots in radio astronomy phenomena where the magnitude of the magnetic fields, electron drifts, and ion distributions differ from those of the hypersonically generated plasma. However, it is possible that judicious alteration of some of the plasma parameters, together with suitable adjustment of associated boundary conditions, can introduce sufficient degrees of similarity to permit application of the electromagnetoionic concepts.

Some experimental difficulties are to be anticipated in application of both the recombination approach and the electromagnetoionic approaches because of the magnitude of the auxiliary electric and magnetic fields which must be employed in order to bring about the desired interactions. However, these are not insurmountable, and proper alteration of assorted plasma parameters may serve to diminish the severity of the imposed field requirements.

ACKNOWLEDGMENT

The author is indebted to C. Honeywell and J. Yashon for formulation of some of the initial concepts outlined in this paper; to A. Bauer for his assistance in outlining portions of the over-all wave-plasma interaction problem; and to D. DeVale and H. E. Moore for compiling and plotting the various equations expressing plasma and wave characteristics. Indebtedness is also expressed to N. Draganjac and V. Reese of the Wright Air Development Center for permission to utilize background material pertaining to Contract AF 33 (616)-6464 with the Admiral Corporation.

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An Analog and Digital Airborne Data Acquisition System[*]

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***Summary*—A highly flexible analog and digital airborne data acquisition system has been designed and developed by Radiation, Inc., for the General Electric Company Flight Test Facility at Edwards Air Force Base, Calif.**

The acquired data is recorded on one-inch tape. The format may be fourteen tracks of analog or seven tracks of analog with sixteen tracks of digital data. Ampex AR-200 equipment is used on the analog subsystem. Complete analog system reference data are recorded on one track.

The digital system has extreme flexibility. From ten to ninety channels may be programmed for individual word rates of from 1.25 samples per second to 2×10^3 samples per second. System word rates are 20 kc, 10 kc, 5 kc, and 2.5 kc. The analog-to-digital converter performs up to 2×10^4 conversions per second, depending on the selected sampling rate of the multiplexer. Time-history and system marker data are also recorded. Provision for acceptance of Gray code digital input data has been made. The input on any channel may be low-level (±10 mv full scale) or high-level (±5 volts full scale). Signal conditioning and automatic calibration are provided. Multiplexer channel capacity can be extended by the addition of more modules. Flexibility of programming is provided with pluggable program boards.

The system is designed using all transistorized components and is constructed to withstand vehicular environmental extremes. Detailed descriptions of the low-level gate circuit, programming, accumulating, and coding techniques are made.

INTRODUCTION

THE introduction of digital techniques to the field of flight testing has offered possibilities of increased flexibility, capacity and accuracy to the flight test engineer. The initial development of the first airborne pulse code modulation (PCM) telemetry was initiated with the development of the AKT-14 for WADC in 1954. Since then, the evaluation of solid state component development and circuit design has led to highly reliable, small, and light-weight data gathering systems. The ruggedness and stability of a system of this type has been proven by the success of the PCM telemeter in use on the rocket sleds at Holloman Air Force Base, New Mexico. The advantages of digital data handling are gained when transmitting over a telemetry link or recording in the vehicle. The accuracy of

[*] Manuscript received by the IRE, December 2, 1959.

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the digital data is easily maintained with the application of either media.

This paper is an attempt to show the unique circuits, logic, and packaging techniques employed by Radiation, Inc., Melbourne, Fla., to meet the in-flight data acquisition system requirements outlined by B. E. Applegate.[1] The system was designed by the General Electric Jet Engine Flight Test Facility at Edwards Air Force Base, Calif. Results of design and development for the digital subsystem are described in the areas of analog signal conditioning and calibration, time-division low- and high-level multiplexing, programming of the electronic multiplexer gates, high resolution amplification, coding, data handling, and recording. The use of magnetic tape for analog and digital data correlation is made possible by the development of a unique digital head by Ampex Corp., Redwood City, Calif. The analog subsystem is primarily a result of development by Ampex and is described in detail by E. P. Brandeis and M. E. Harrison.[2]

SYSTEM DESCRIPTION

The over-all data acquisition system consists of both analog and digital subsystems. Fig. 1 indicates the major blocks that are required to form the complete system. Subsystem *A* (Analog) is above the dotted dividing line and subsystem *D* (Digital) is composed of those blocks below the line. Since the components of the analog subsystem (subsystem *A*) are adequately described in a previous technical paper,[2] no details of the components will be furnished except where required for a clear understanding of the over-all system operation. Each component of the digital subsystem (subsystem *D*) will be described in varying detail, the extent of which will depend on the uniqueness of circuit design, logic, or packaging techniques conceived in the development of that component. the following are the major specifications of the digital subsystem:

1) *Electrical Specifications*

Over-all System Accuracy	±0.2 per cent referred to full scale input
Input Signal Levels	±10 mv, ±5 volts
Word Rates	20 kc, 10 kc, 5 kc, 2.5 kc
Sampling Rate Range	2×10^3 to 1.25 samples per second
Programming	Variable

2) *Environmental Specifications*

Temperature	−55°C to +71°C
Altitude	100,000 feet
Vibration	5 to 50 cps @0.060 inch (*DA*) 50 to 500 cps @0.010 inch (*DA*), 10g maximum
Shock	10g in all directions
Power	400 cps ±20 per cent −115 volts ±20 per cent

The primary considerations in the design of the signal conditioning and calibration circuits were flexibility, simplicity and reliability. No active components are used since only attenuation of input signals is required. Flexibility is obtained by an arrangement of terminals on a card which allows the interconnection of points within the circuits. The configuration of the wiring may be tailored to accept one of the three basic types of measuring devices: 1) bridge type transducer, 2) thermocouple, and 3) potentiometer. Adjustment of resistor values may be made, if necessary, to bring the signal within the measurable range of the system for the various signal levels expected from wide variations in transducer characteristics and parameter excursions. Calibration signals, also variable, are furnished for

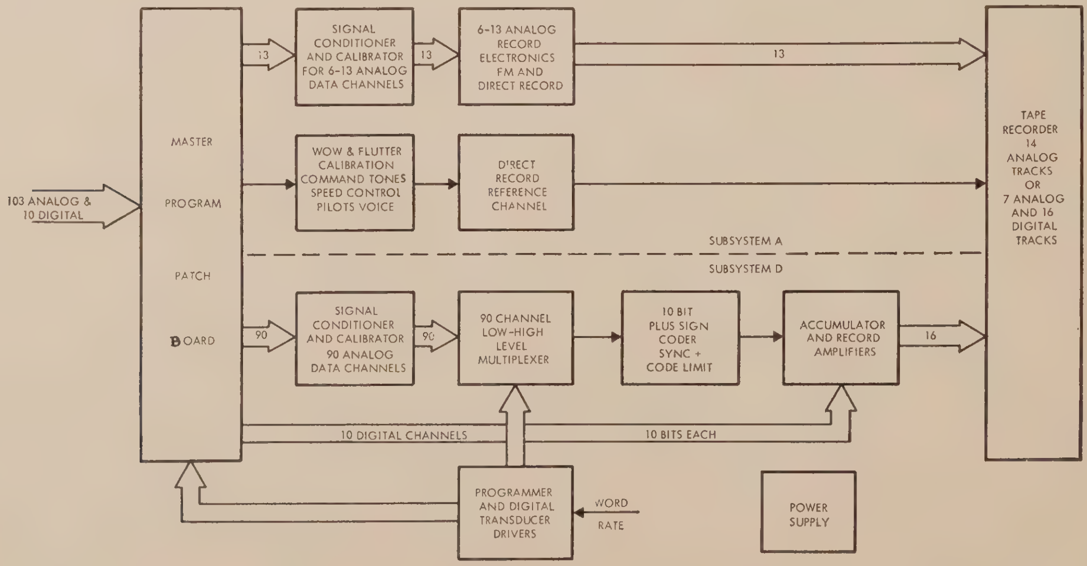
103 ANALOG & 10 DIGITAL
MASTER PROGRAM PATCH BOARD
13
SIGNAL CONDITIONER AND CALIBRATOR FOR 6-13 ANALOG DATA CHANNELS
13
6-13 ANALOG RECORD ELECTRONICS FM AND DIRECT RECORD
13
WOW & FLUTTER CALIBRATION COMMAND TONES SPEED CONTROL PILOTS VOICE
DIRECT RECORD REFERENCE CHANNEL
SUBSYSTEM A
SUBSYSTEM D
90
SIGNAL CONDITIONER AND CALIBRATOR 90 ANALOG DATA CHANNELS
90
90 CHANNEL LOW-HIGH LEVEL MULTIPLEXER
10 BIT PLUS SIGN CODER SYNC + CODE LIMIT
ACCUMULATOR AND RECORD AMPLIFIERS
16
TAPE RECORDER 14 ANALOG TRACKS OR 7 ANALOG AND 16 DIGITAL TRACKS
10 DIGITAL CHANNELS
10 BITS EACH
PROGRAMMER AND DIGITAL TRANSDUCER DRIVERS
WORD RATE
POWER SUPPLY

Fig. 1—Analog and digital data acquisition system.

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functional checking of the entire airborne system and eventual data correction, if required, by the ground data handling system. The calibration signals for the digital subsystem channels are derived from the transducer drive voltage supply and therefore provide a check on that component of the system. Transducer voltages of both polarities are provided for calibration of selected channels in the negative region for a complete system linearity check. Calibration of the analog subsystem channels is required for compensation of the ground recovery components due to drift in the airborne recording equipment. The FM record channels are calibrated at zero and 80 per cent of maximum excursion with voltage from the transducer supply. The direct record channels are calibrated at only full-scale level. The voltage source is a 10.5-kc crystal-controlled oscillator which is also used for a full-scale calibration tone on the reference channel. An 11.7-kc tone is recorded on the reference channel to indicate a zero calibration period. Signal conditioning for these channels is accomplished with circuits identical to those in the digital subsystem.

The transducer voltage source is highly regulated and stabilized over the range of ambient temperature excursion. A unique feature of the supply is that the reference is derived from the coder weighted current reference voltage supply. Excursion of the coder reference tends to be compensated by a related excursion of the transducer supply voltage.

The multiplexing and programming portion of the digital subsystem consists of seven modules. Six of these modules are multiplexers which contain the gates and amplifiers. The seventh module is the programmer. Each multiplexer module contains fifteen gates which are universal in that they may be used for low- or high-level gating. Low-level for this system is defined as the range ±10 mv. High-level is defined as the range ±5 volts. The low-level signals are amplified after multiplexing. There is one amplifier in each multiplexer module which amplifies the ±10-mv signals to the high-level ±5-volt level. The multiplexing and programming system was designed with the greatest flexibility feasible within the practical hardware size limitations.

Fig. 2 is a block diagram of one multiplexer module. Each low-level gate is queried individually from the programmer. Ten digital transducers, such as shaft encoders, may be queried by the programmer instead of any ten multiplexer gates. One type of gate switches either high- or low-level input information. Provision is made to route the low-level signals through the amplifier and route the high-level signals to bypass the amplifier. The amplified low-level signals are again multiplexed onto the final multiplexer buss with the signals originally high-level, and with similar signals from the other five multiplexer modules through a standard gate used in this case as a high-level gate. The gate is electronic and is composed of silicon transistors. The configuration is discussed in some detail later in the paper.

A frame of digital information recorded on the tape contains data calibration signals, range time, and unique word markers in the positions as shown in Fig. 3.

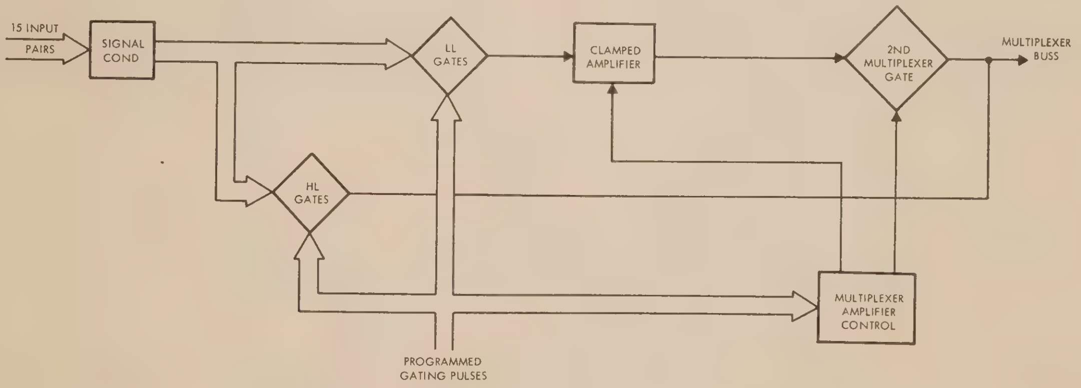
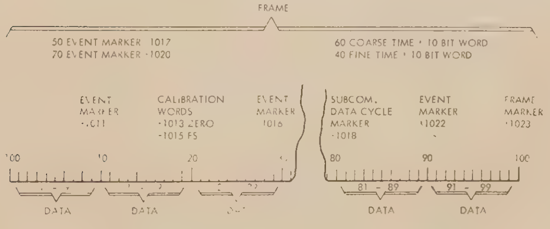

15 INPUT
PAIRS
SIGNAL COND
LL GATES
CLAMPED AMPLIFIER
2ND MULTIPLEXER GATE
MULTIPLEXER BUSS
HL GATES
MULTIPLEXER AMPLIFIER CONTROL
PROGRAMMED GATING PULSES

Fig. 2—One multiplexer (of six). Block diagram.


FRAME
50 EVENT MARKER 1017
70 EVENT MARKER ·1020
60 COARSE TIME · 10 BIT WORD
40 FINE TIME · 10 BIT WORD
EVENT MARKER ·1011
CALIBRATION WORDS ·1013 ZERO ·1015 FS
EVENT MARKER 1016
SUBCOM. DATA CYCLE MARKER ·1018
EVENT MARKER ·1022
FRAME MARKER ·1023
00
10
20
80
90
100
81 - 89
91 - 99
DATA
DATA
DATA
DATA

SUPERCOMMUTATED CHANNELS USE EVENLY SPACED TIME POSITIONS IN THE FRAME. I.E., SCC # X MIGHT BE IN TIME POSITIONS 7, 37, 57, 77, & 97

Fig. 3—Frame format.

Plus 5-volt and minus 5-volt transducer power supplies are provided in the system. The current available from each of these power supplies is one ampere and regulation is 0.05 per cent. Provision has been made in the multiplexers for the signal conditioning described above.

The analog-to-digital conversion unit has evolved from many designs for both airborne and ground PCM systems. The unit is completely solid-state, packaged in a volume of about 400 cubic inches. The coder receives the multiplexed, amplified, amplitude-modulated analog sample of about 41 μsec width. Sample and hold circuitry at the input of the coder selects a six-μsec increment near the end of the multiplexed sample, and holds the average amplitude of that sample to within the tolerance required. The output of the analog-to-digital converter is a serial eleven-bit binary code limited to a maximum of 2032 for plus five volts input and a minimum of 0016 for minus five volts input. The maximum word rate is 20 kc, but slower command rates may be selected manually at the programmer. The bit rate of the coder is crystal-controlled at 280 kc.

All data are brought together in the module called the accumulator. System data are generated within this module. The 30-card module performs a total of eleven different functions in one register and peripheral circuits. The module contains the digital recording amplifiers and the time-history generator. Eleven-bit serial code is transformed to ten-bit plus sign, or folded code. A serial-to-parallel conversion is performed. Digital input data are routed into the PCM subsystem directly into the accumulator register. Digital input data are commonly in Gray code form, so a Gray to binary conversion is performed (in the register). Unique words are generated within the accumulator. These are words that mark frame time position, subframe time position, external events, and calibration cycles of several seconds. All necessary gating circuits to bring all digital data together into one register are provided. Parity is generated from serial folded code and from parallel-to-serial converted digital words.

All system control circuits are located in the accumulator. These provide the sequential calibration signals and control the time-history generator. The switches are located within the programmer module so that all access to the system in preflight need be made only at the programmer and multiplexer units.

The digital recording is accomplished by gating information from the parallel code register into the record amplifiers which drive a center-tapped special 16-track digital head in a nonreturn-to-zero pattern. The recording of a binary "one" is accomplished by a reversal of current flow in the head to give a change of flux linking the tape. No current reversal is made at the word position if a "zero" is to be recorded. The record amplifier is basically a current driving flip-flop configuration driven in a complementing mode by the code gating pulse.

Analog data recording is accomplished in two possible modes. High-frequency data may be recorded on up to thirteen direct record tracks, and low-frequency signals may be recorded on up to thirteen tracks of FM recording. System data such as servo speed control, wow and flutter reference, pilot's voice, and calibration tones are recorded on one direct record track. Tones for zero and full-scale calibration indications are mixed with the other reference signals during the calibration cycle, which is determined by the accumulator. The tape format is shown in Fig. 4. Fig. 5 shows the analog and digital head layout and track numbering.

The concept of packaging used in this system is Radiation, Inc., standard airborne packaging with minor modifications.[3] The packaging utilizes a card size of four and one half inches wide by five and one half inches deep. The tray that holds the cards varies in length for the various modules depending on the number of cards required. Fig. 6 is a standard module of this system. It can be seen that all cards, connectors, and controls are accessible from one face of the module. The connectors are located on the recessed ledge. The front of the box can be removed allowing access to the cards, test points, adjustments, and local controls (if any).

Fig. 7 is a picture of a card. The cards are clamped with a mechanism which also bows them slightly for use in a vibrational environment. Maintenance can be performed on the cards by the use of extension racks which allow a card to be brought forward out of the box, yet still plug into the chassis wiring. Test points are available on the cards which facilitate the determination of faulty cards in maintenance.

Accessory plugs are provided in each module of the system for attachment of checkout cart electronics. The analog subsystem and the Ampex airborne AR-200 transport are packaged in Ampex standard airborne modules.

DETAIL DESCRIPTION

The most significant points of interest from the standpoint of unique circuit design and logic arrangement are discussed in detail in the following sections.

Low-Level Switch

The low-level switch or gate used is a development outgrowth of the original germanium transistor switch reported by Dorsett and Searcy.[4] Since this time, the improvements made have been those of drive, circuit configuration, and the use of now available silicon transistors. Fig. 8 is a general schematic diagram of the low-level gate. This gate, without any changes, is also used as the high-level gate providing an increase in our system flexibility. Both sides of the double-ended input

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[3] W. A. Corry, "Printed Circuit Packaging for Environmental Extremes," presented at the 1958 National Telemetering Conference, Baltimore, Md.

[4] E. A. Dorsett and J. H. Searcy, "Low-level electronic switch," 1956 IRE NATIONAL CONVENTION RECORD, pt. 5, pp. 57–61.

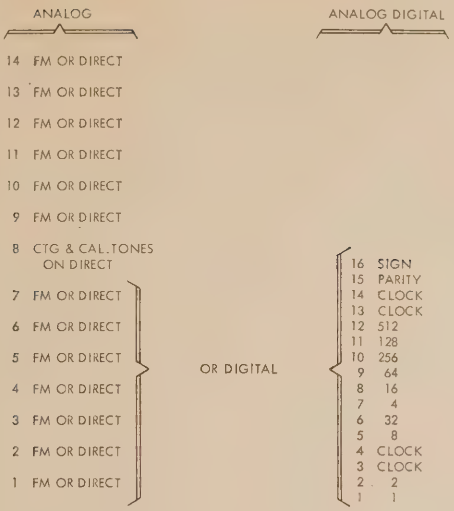
ANALOG
ANALOG DIGITAL
14 FM OR DIRECT
13 FM OR DIRECT
12 FM OR DIRECT
11 FM OR DIRECT
10 FM OR DIRECT
9 FM OR DIRECT
8 CTG & CAL. TONES ON DIRECT
7 FM OR DIRECT
6 FM OR DIRECT
5 FM OR DIRECT
4 FM OR DIRECT
3 FM OR DIRECT
2 FM OR DIRECT
1 FM OR DIRECT
OR DIGITAL
16 SIGN
15 PARITY
14 CLOCK
13 CLOCK
12 512
11 128
10 256
9 64
8 16
7 4
6 32
5 8
4 CLOCK
3 CLOCK
2 2
1 1

Fig. 4—Tape format chart.

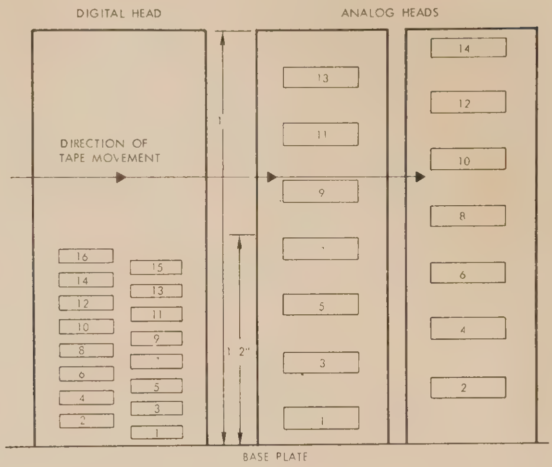
DIGITAL HEAD
ANALOG HEADS
DIRECTION OF TAPE MOVEMENT
14
13
12
11
10
9
8
6
5
4
3
2
1
16
14
12
10
8
6
4
2
15
13
11
9
5
3
1
1
1 2"
BASE PLATE

Fig. 5—Head format.

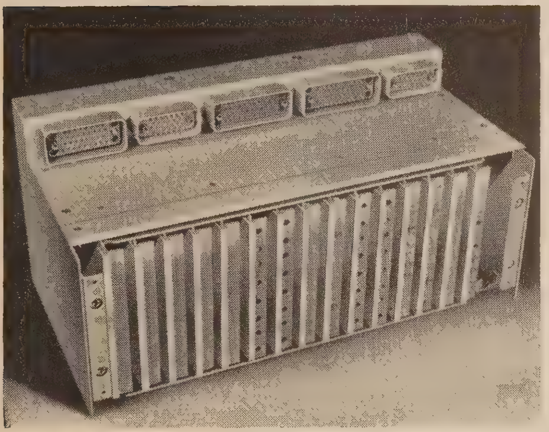

Fig. 6—Multiplexer module.

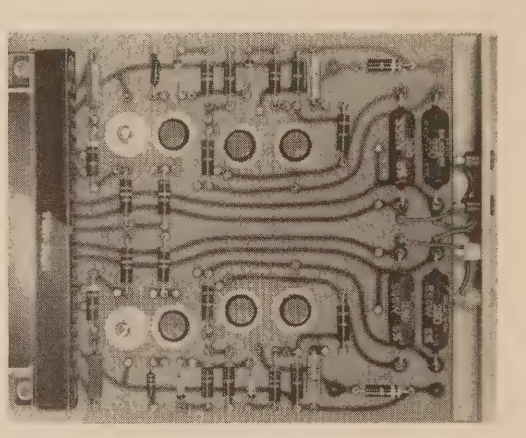

Fig. 7—Photograph of typical card.

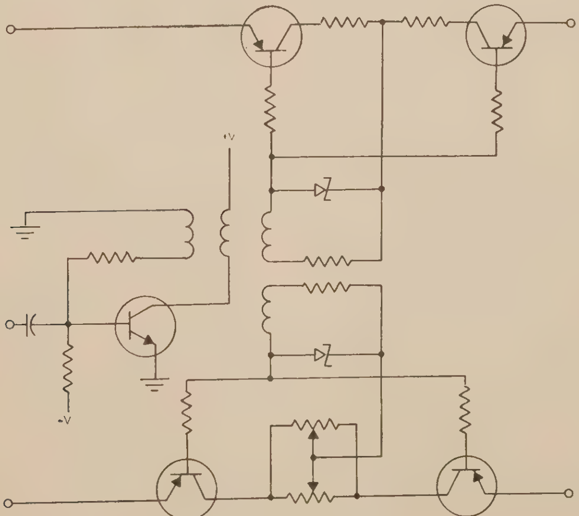

Fig. 8—Low-level gate schematic.

are gated. This is done so that transformers are not required for coupling into the succeeding circuitry. Common mode problems necessitate the use of either a transformer or switching both sides of the line. Transformers which are satisfactory for coupling and yet meet the airborne environmental requirements are not available. The driving circuit is a regenerative transformer coupled amplifier; that is, a blocking oscillator which is turned off before the transformer saturates. Care is taken to maintain the keying signal as a flat-top pulse. This is done by zener regulator circuits in the switch driving circuitry.

There are at least five transistors on the market presently that can be used as the switching transistors. The important parameters are low saturation resistance (low enough so that it is not in an appreciable fraction of the transducer impedance), low-off leakage current (from collector to base) and reasonably low emitter resistance. It has been found that the particular transistors used perform better as a low-level switch if they are used in the inverted connection; that is, the driving signal is applied across the collector-base diode. Each side of the switch contains two transistors. These are provided so that keying signal leakage will be effectively cancelled out. Further, the arrangement of the two transistors "back to back" in each signal line insures that a nonconducting gate will not conduct through forward biased transistor diodes under certain possible cases of voltages applied across the gate terminals.

Even with the availability of silicon transistors some temperature control is still required. However, temperature requirements are not as exacting as they were with the germanium switch. Temperature stabilization is required to minimize keying signal offset compensation drift. This drift has been found to be 0.5 μv per degree Centigrade. It is evident that only temperature excursions of more than 20°C would affect the system accuracy to the extent of one increment or one bit. Controlled heaters regulate the temperature to ± 5°C. Temperature regulation would not be needed in a controlled environment, or in systems which have a resolution of 20 or 30 μv per bit.

Programming

The multiplexer is the programmed type. Programmable means that the sampling rate per channel and the number of channels can be changed and fitted to match a particular application. This type multiplexer permits an acquisition system to be highly flexible. However, when one begins to think about flexibility and its desirability, the problems and consequences of flexibility must also be considered. Flexibility, size, and simplicity of operation often are not compatible. When flexibility and automatic operation are required, size often becomes prohibitive and definitely inconsistent with vehicular system requirements. Therefore, a system that is optimum, that is, a system that meets all requirements in the best possible manner, will result only if the amount of flexibility needed is determined and specified in advance. Often, unwieldy and unusable systems are the result of buyer's specifications being too stringent and the vendor's reluctance or inability to negotiate a suitable system compromise.

The customer for this system, the General Electric Flight Test Facility at Edwards Air Force Base, has been quite cooperative in setting up system specifications and system requirements so that a system could be designed that meets operational requirements and yet is a reasonable size. For instance, flexibility in programming without any restrictions would require that sampling rates of any number be possible. It is immediately obvious that such a system would not be practical. General Electric supplied the required sampling rates. The total number of programs required to be capable of immediate use, and the number of channels and each channel's sampling rate within each of these programs was specified. The sampling rates required in the various programs are always included in the five sampling rates that were originally specified. The most extensive program that might be required at some future time was determined so that the proper amount of hardware could be put in the system. The system requires the capability for a large number of different programs, the ability to change programs in a reasonably short time (five minutes) and that a substantial number of programs be purchased with the original system. To meet the requirements stated above, a program system in which electronics may be moved from logical position to logical position and may be used in a different position for each program was developed. The actual programming is accomplished by changing the chassis wiring of the programming section of the system permitting the system to be relatively inexpensive since the same electronics is used on each program.

Fig. 9 is a block diagram of the programming method used. A countdown from the total multiplexer system sampling rate to the lowest channel sampling rate is provided. In the process of this countdown, care is taken that each of the desired sampling rates of the total system is available. Matrices are attached to the countdown circuit. These provide the output "phases" of the sampling rates desired. The number of phases available at each of these rates is the amount of countdown from the preceding sampling rate. The above described circuitry is common to all programs for the programmer.

The circuitry now to be described changes for each program. Fig. 9 is a block diagram of program X. Fig. 10 is the block diagram of program Y. The number of phases from two adjacent sampling rates are combined in an array of "and" gates so that all possible combinations are made. This produces a number of pulses at the slowest of two sampling rates, and the number of these phases will be the product of the number of the two input sampling rate phases. This mechanism is repeated from the two fastest sampling rates on to the slowest sampling rates. Wherever a particular sampling rate,

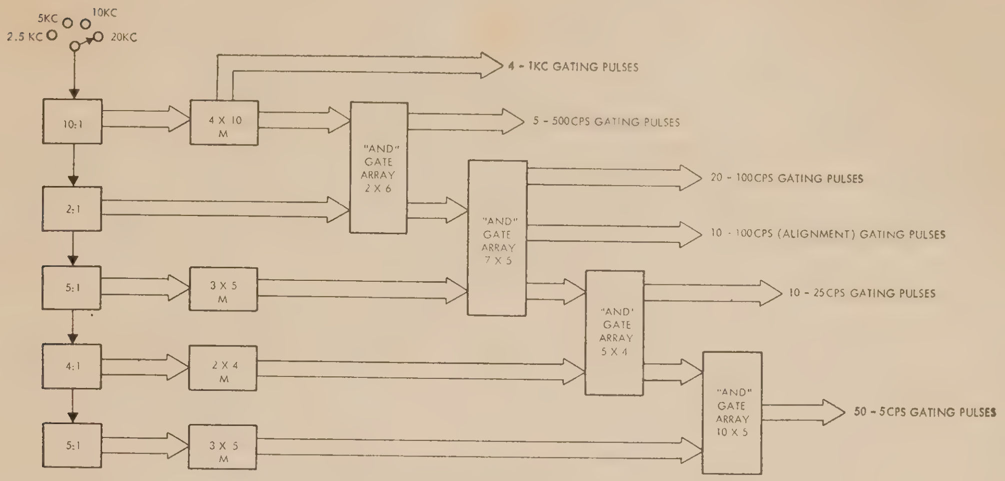
5KC
10KC
2.5 KC
20KC
4 - 1KC GATING PULSES
10:1
4 X 10 M
5 - 500CPS GATING PULSES
"AND" GATE ARRAY 2 X 6
20 - 100CPS GATING PULSES
2:1
"AND" GATE ARRAY 7 X 5
10 - 100CPS (ALIGNMENT) GATING PULSES
5:1
3 X 5 M
10 - 25CPS GATING PULSES
"AND" GATE ARRAY 5 X 4
4:1
2 X 4 M
"AND" GATE ARRAY 10 X 5
50 - 5CPS GATING PULSES
5:1
3 X 5 M

Fig. 9—Programmer with program *X*. Block diagram.

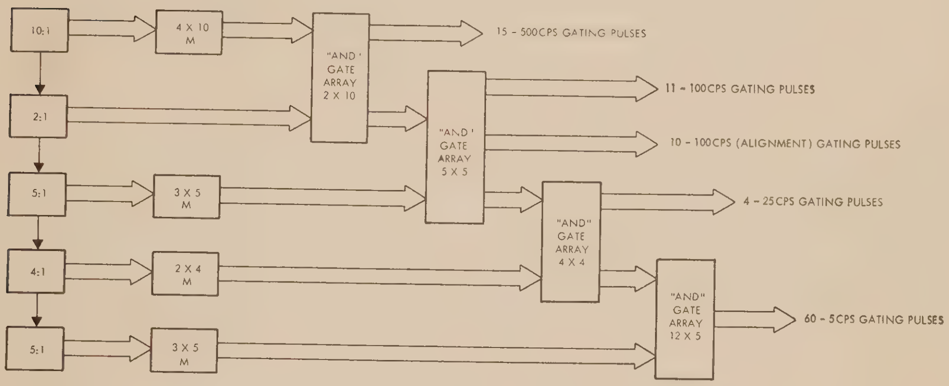
10:1
4 X 10 M
15 - 500CPS GATING PULSES
"AND" GATE ARRAY 2 X 10
11 - 100CPS GATING PULSES
2:1
"AND" GATE ARRAY 5 X 5
10 - 100CPS (ALIGNMENT) GATING PULSES
5:1
3 X 5 M
4 - 25CPS GATING PULSES
"AND" GATE ARRAY 4 X 4
4:1
2 X 4 M
"AND" GATE ARRAY 12 X 5
60 - 5CPS GATING PULSES
5:1
3 X 5 M

Fig. 10—Programmer with program *Y*. Block diagram.

especially one of the higher sampling rates, is desired, it is taken out of the system when generated instead of continuing down the pyramid of "and" gates. Comparison of the block diagrams of programs *X* and *Y* indicates that only rewiring is necessary when changing from one program to another. Rewiring has been accomplished by providing a wired bracket into which the standard cards of the system are plugged. This bracket is separate from the ordinary chassis wiring of the module and it in turn plugs into the module wiring. Therefore, in essence only a portion of the chassis wiring is altered in changing from one program to another. Output of the program wiring to the main chassis wiring determined the position of each input gate or channel which is controlled by a particular program pulse. As set up, this is not to be changed. However, if necessary, the large connector between the program wiring and the main chassis wiring could be altered to change the channel destination of the programmed sampling rate. In fact, the choosing of any ten inputs to be digital instead of analog is accomplished by the rewiring of this connector. The rewiring is facilitated by providing a connector with taper pin connections.

Low-Level Amplifier

A common amplifier is used for fifteen multiplexed channels. Amplification could be done prior to multiplexing through the use of conventional dc amplifiers on each channel. It is apparent that a prohibitively large number of amplifiers would be required. There are basic differences between the signal to the conventional dc amplifier and the signal to the one required in this system. The frequency spectrum of the multiplexed signal is much higher than that of the transducer signal, the source impedance varies from one channel to the next, and the common-mode signal level may vary from channel to channel.

The amplifier shown in Fig. 11 is essentially a direct-connected transistor differential amplifier utilizing periodic clamps for restoration of direct voltage and current levels. The six amplifiers are time-shared to provide the necessary periodic intervals for clamping between sampled data inputs. The input stage consists of a pair of base-fed transistors connected as a differential amplifier. High input impedance and gain stability are improved by inserting resistance in the emitters of the differential pair, while common-mode rejection is

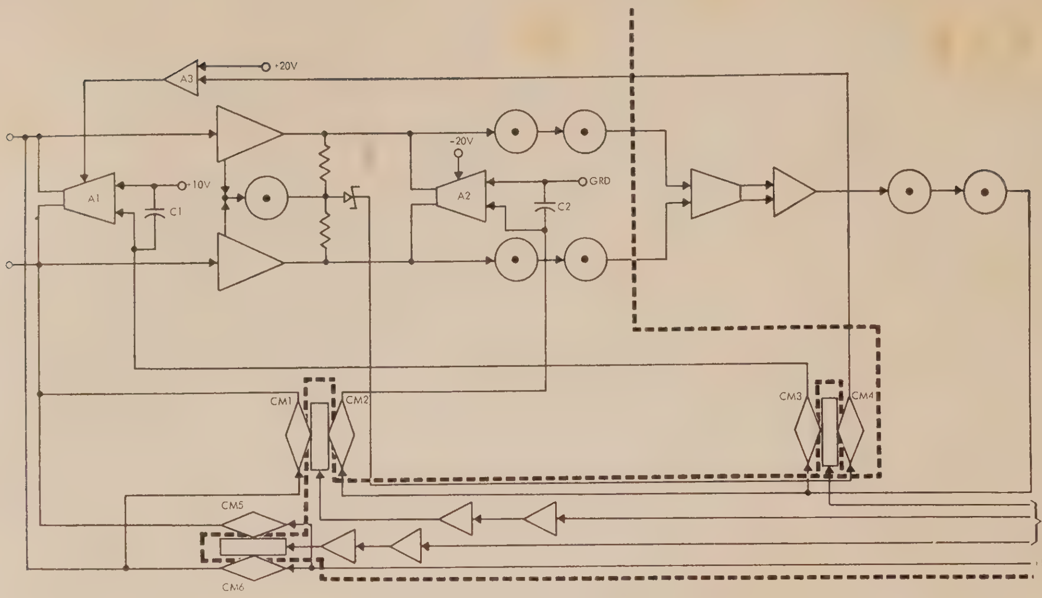

Fig. 11—Clamped amplifier. Block diagram.

gained by feeding the common-mode signal from the common emitter connection to the out-of-phase collector. The input impedance is 30K ohms when the amplifier gain is 500. Noise referred to the input is ten μv and the bandwidth is 100 kc. The input stage is temperature regulated within ±5°C over the ambient range for stability.

The balance of the circuit is basically a group of double-ended amplifier stages with emitter followers for impedance matching forming a feedback amplifier. Drift is prevented by the use of voltage and current clamps in the direct connected circuit. Gate circuits are used to provide the necessary switching functions during the clamping periods. With reference to Fig. 11, the voltage clamp is accomplished by closing two gates, one to short circuit the input (CM1), and the other to connect the output voltage to a comparison circuit (CM2). If the output is not zero, a negative feedback is applied to the collectors of the first stage which drives the output to zero. The voltage at the comparison circuit is stored on C2 so that the level is maintained constant between clamping intervals.

Current drift, as well as voltage drift, may occur in a direct-connected amplifier. With the multiplexer gates nonconducting, the output voltage is switched (CM3) into a differential drive circuit and a constant current is applied at both input circuits and the value of the current to each input is adjusted automatically (A1) to cause the output to go to zero. The total value of the current is adjusted by comparison (CM4) of the first stage output with a known reference in A3. The value of the current is maintained between clamping intervals by storage of the output level on C1.

In addition to the voltage and current clamps, a third restoration process is required. Since the source varies as the channels are sampled, common-mode signals will change with channels. Common-mode crosstalk results due to the requirement for charging distributed capacitance in the gating circuilts. The process consists of bringing the multiplexer output terminals to a voltage more positive (+10 v) than the peak of any common-mode signal with CM5 and CM6, thereby charging the distributed capacity of the gates through the emitter-to-base junction, then returning the clamp voltage to ground prior to sampling.

Four distinct amplifier clamping periods are required: 1) current clamp, 2) voltage clamp, 3) and 4) common-mode clamp. Programming is arranged so that the four clamp periods are available in two sampling periods between data samples while a different amplifier is activated.

Analog-to-Digital Converter

The analog-to-digital converter (coder) used in this airborne acquisition system is the Radiation Inc. standard product designed for use in vehicular environments. This airborne coder is fully transistorized, is ruggedized sufficiently well to withstand sled environments as well as airborne environments, and is composed of silicon transistors throughout. Earlier models of the coder have been discussed in several papers[5,6] in the literature previously. Its mode of conversion is that which is popu-

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[5] L. S. McMillian,“ Development of a high-speed transistorized 10-bit coder,” 1957 WESCON CONVENTION RECORD, pt. 5, pp. 73–76.

[6] R. E. Marquand and W. T. Eddins, “A transistorized PCM telemeter for extended environments,” 1957 WESCON CONVENTION RECORD, pt. 5, pp. 76–81.

larly known as "Half-Split Technique" or as a digital-to-analog converter with digital feedback.

The coder contains the conventional Radiation Inc. sample and hold circuitry modernized to meet the new vehicular requirements. Earlier models or configurations of this sample and hold circuitry have been discussed in the literature.[7] The ouput of the coder is in the form of a serial code with available word and frame sync, since the coder is a basic unit performing enough functions for use with an RF link. Provision has been made to limit the full scale of the coder to less (±1008) than that possible with eleven bits (±1023). Other functions which might be considered to be part of the coder, such as the generation of parallel code, parity, and folded code (10 bit plus sign) are performed in the accumulator.

Fig. 12 is a block diagram of the coder. It can be operated in either the free-running (which means continuous) or commanded mode. The rate at which the binary digits are coded is kept constant at 280 kc. It takes 43 μsec to code each word. Since this system operates at 20 kc, 10 kc, 5 kc, or 2.5 kc, the coder is commanded every 50, 100, 200, and 400 μsec respectively. The coding time is fixed at 43 μsec and the remaining μsec before the next coding period is dead time.

The logical decisions to retain or reject the binary weighted reference currents while sending in the next smaller current are made in sequence. Sequential pulses on separate lines are therefore necessary. A feedback Gray code counter is used for this application rather than the ordinary binary counter. This type of counter has the following advantages: 1) there is no delay of forward carry as in the binary counter, and 2) the fastest operating flip-flop need run at a rate of only one half that of the corresponding flip-flop in a binary counter. The electronics necessary for feedback is available with either counter since a sorting matrix is necessary to obtain the number of pulse lines desired. A broken ring counter was not used because of the amount of electronics required.

A method of describing the conversion cycle is to state that the coder generates a reference analog within itself in successively smaller binary steps, these reference analogs being summed together with the input analog current-wise and then successively compared to signal ground. The logical operations involved in the coder are to generate a binary weighted reference analog, sum it with the input analog, compare it to signal ground, reject or retain this first reference analog dependent upon the comparator's decision, and switch into the reference analog just determined, another binary reference analog of half the magnitude of the preceding reference analog. Thus, the coder successively tried to match (in opposite polarity) the input analog in binary steps from most significant to least significant by retaining some steps and rejecting others. Fig. 13 is a schematic of the summing network. It is a current device and as such contains precision resistors so that accurate weighted currents may be summed. The voltage from which these currents are generated must be of a greater precision and accuracy than the least significant bit of the number of bits generated in the coder. Transistors are used to switch the precision summing currents into the current summing network.

An analog-to-digital converter of the type just described (or most types) must contain analog circuitry that is more accurate than the number of digits or binary increments into which the input analog can be quantized. Therefore, an eleven-bit coder or ten-bit plus sign, where the eleven bits are binary, implies 2047 possible quanta against which the input analog is compared. One part in 2000 is equal to 0.05 per cent of full-scale accuracy. Therefore, the analog circuitry such as the reference power supplies and sample hold circuitry must be accurate to some greater precision. The analog portions of this coder meet these requirements.

Since the coder must maintain extremely accurate analog signals, some temperature control is required. Such circuits as the comparator, sample and hold, precision reference power supplies, and the most significant digits of the summing network must be temperature controlled to some extent. The control required to maintain sufficient accuracy is plus or minus five degrees Centigrade over the range of ambient temperature excursion. Heaters and control circuitry are provided in the coder.

Accumulator

A block diagram of the accumulator is shown in Fig. 14. The accumulator unit performs the following functions:

1) Folding code
2) Serial-to-parallel conversion
3) Parity generation
4) Parallel-to-serial conversion
5) Unique word generation
6) Word rate and time history
7) Digital input gating
8) Gray-to-binary conversion
9) Parallel storage
10) Recording
11) Calibration control

Most of the circuitry involved is conventional digital type configurations, but it is felt that the arrangement of these circuits to perform the listed functions represents a maximum usage of a minimum number of components.

The logic for folding (transforming an eleven-bit code to ten-bit plus sign) the serial code from the coder is an inverse exclusive "or" circuit. The simplified Boolean expression to be mechanized is $AB+\overline{(A+B)}$ where A

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[7] W. T. Eddins, "Sample-and-hold circuits for time correlations of analog-voltage information," 1958 Wescon Convention Record, pt. 5, pp. 21–26.

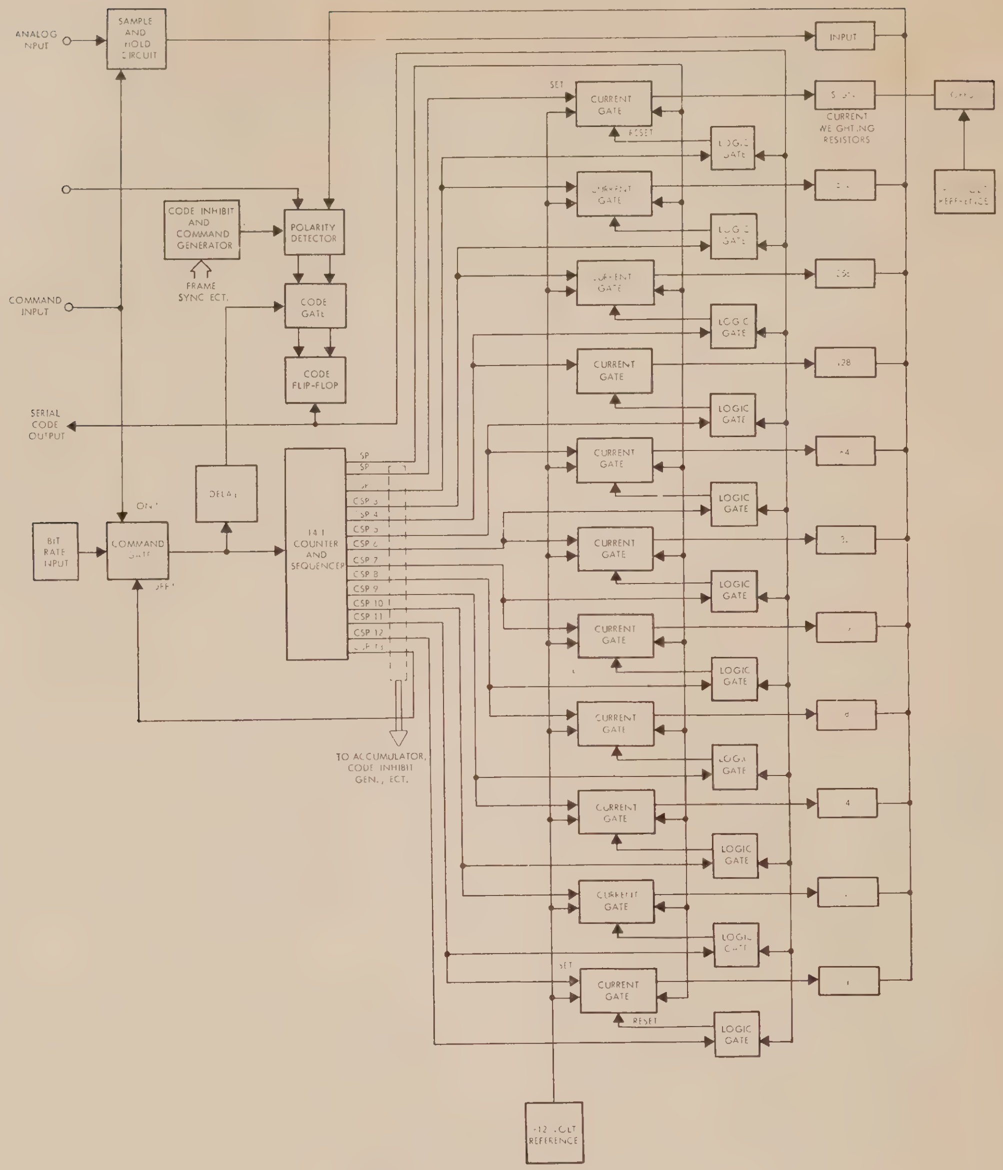
ANALOG INPUT
SAMPLE AND HOLD CIRCUIT
INPUT
SET
CURRENT GATE
RESET
LOGIC GATE
CURRENT WEIGHTING RESISTORS
CODE INHIBIT AND COMMAND GENERATOR
FRAME SYNC ECT.
POLARITY DETECTOR
COMMAND INPUT
CODE GATE
CODE FLIP-FLOP
SERIAL CODE OUTPUT
DELAY
ON
OFF
BIT RATE INPUT
COMMAND GATE
14:1 COUNTER AND SEQUENCER
SP
SP
CSP 3
CSP 4
CSP 5
CSP 6
CSP 7
CSP 8
CSP 9
CSP 10
CSP 11
CSP 12
128
4
TO ACCUMULATOR, CODE INHIBIT GEN., ECT.
+12 VOLT REFERENCE

Fig. 12—Coder. Block diagram.

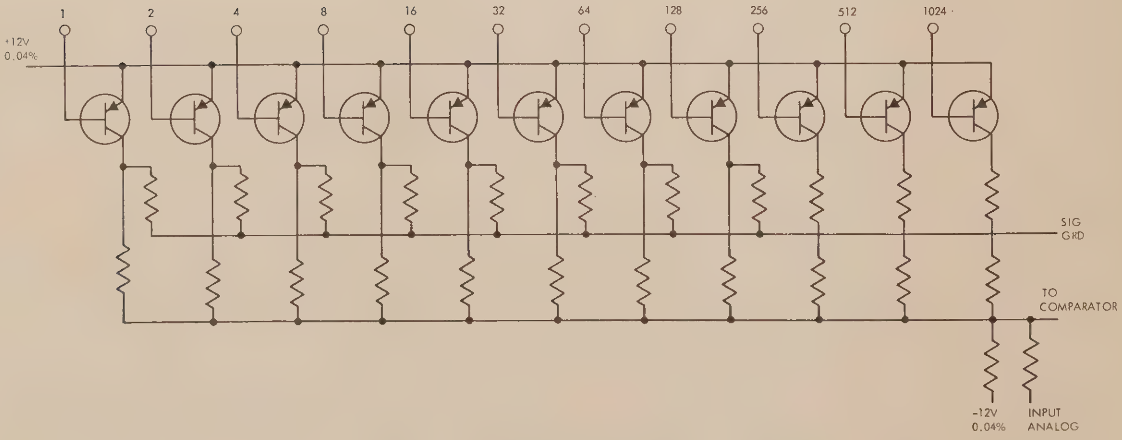
1
2
4
8
16
32
64
128
256
512
1024
+12V 0.04%
SIG GRD
TO COMPARATOR
-12V 0.04%
INPUT ANALOG

Fig. 13—Current summing network. Schematic.

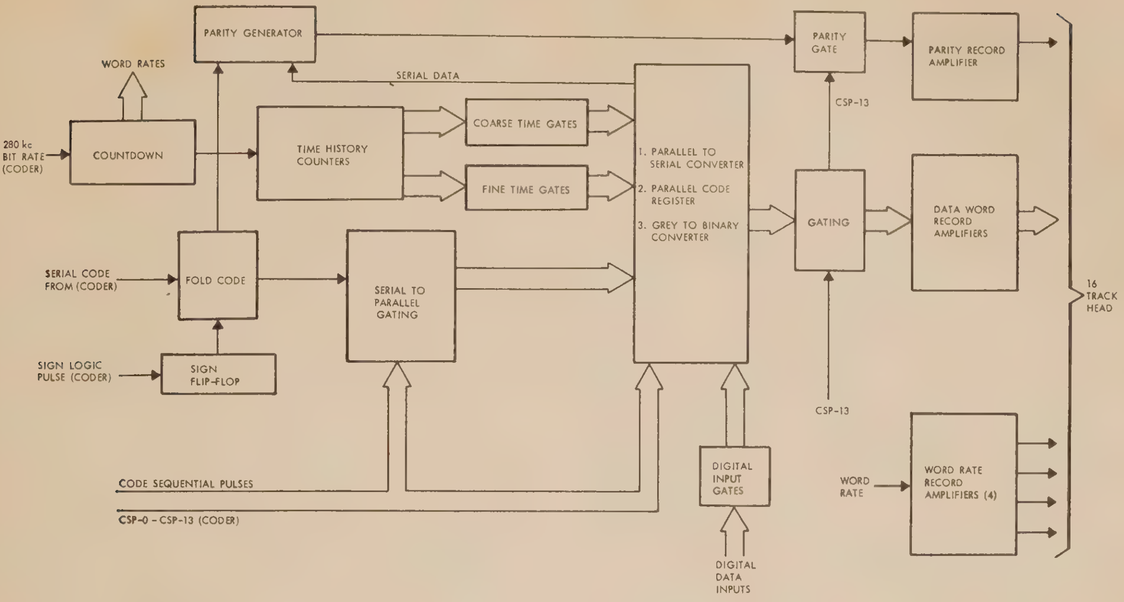
PARITY GENERATOR
WORD RATES
SERIAL DATA
PARITY GATE
PARITY RECORD AMPLIFIER
CSP-13
280 kc BIT RATE (CODER)
COUNTDOWN
TIME HISTORY COUNTERS
COARSE TIME GATES
FINE TIME GATES
1. PARALLEL TO SERIAL CONVERTER
2. PARALLEL CODE REGISTER
3. GREY TO BINARY CONVERTER
GATING
DATA WORD RECORD AMPLIFIERS
SERIAL CODE FROM (CODER)
FOLD CODE
SERIAL TO PARALLEL GATING
16 TRACK HEAD
SIGN LOGIC PULSE (CODER)
SIGN FLIP-FLOP
CSP-13
DIGITAL INPUT GATES
WORD RATE
WORD RATE RECORD AMPLIFIERS (4)
CODE SEQUENTIAL PULSES
CSP-0 - CSP-13 (CODER)
DIGITAL DATA INPUTS

Fig. 14—Accumulator. Block diagram.

and *B* are the sign and data word, respectively. A minimum of logic elements is used as shown in Fig. 15. The purpose of folding code is to give a representation of numbers which is easily understandable by the human operator. The code zero corresponds to zero signal and the code value increases from that point with any change in signal and the most significant bit indicates the sign.

Serial-to-parallel conversion is accomplished by "and" gating the sequential pulses generated in the analog-to-digital converter with the folded serial code into the parallel storage register.

Parity generation for the serial code word is accomplished by gating the delayed clock from the coder with the code to drive the complement input of the parity flip-flop (PFF). Since the PFF is preset to a fixed condition prior to the occurrence of each data word, sampling the condition of the PFF at the end of the word allows the parity bit to be set to a "one" if the "ones" total is even. Parity computation for the digital inputs which are introduced into the parallel code register broadside is accomplished with a parallel-to-serial conversion and "one" counting in the same circuit. The coder output is inhibited during this process.

Unique words are used as markers in the system to indicate to the ground data processing that some event has taken place. A specific word, above the limited full-scale code, is recorded on the tape in a unique time slot to indicate: 1) beginning of a frame of data, 2) beginning of a data cycle, 3) calibration (zero and full scale), and 4) other events as required by system operation. The markers are generated by gating a voltage (indicating a "one") into the proper bit of the parallel code register with the proper program timing pulse.

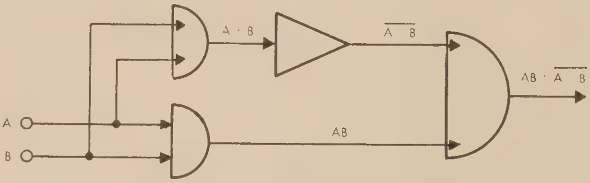
A · B
A B
AB · A B
A
B
AB

Fig. 15—Fold code logic. Block diagram.

Digital counting techniques are used to achieve the various word rates and the time-history rate of 100 pps. Synchronous, stable pulse frequencies are obtained from the single crystal-controlled oscillator in the coder. The same source is used for the coder bit rate. A selector switch at the programmer module is used for selection of the various word rates which drive the programmer counters and control the coding process. The time-history is an accumulation of binary counts in two 1000 to 1 counters. The fine and coarse time words represent a maximum accumulation of ten seconds and 10,000 seconds, respectively. The two time words are gated into the parallel storage register with the proper timing pulses from the programmer.

Gating of the inputs from digital shaft encoders is accomplished simply by "or" gating the ten-bit parallel signals into the parallel storage register. The timing is controlled from the programmer digital query driver, and any channel time position may be used for digital information because of the ability to "patch" timing pulses to the encoder drivers.

Since the most desirable digital shaft encoders generate the digital data in Gray code, it becomes necessary to convert to binary coding prior to recording. A very economical solution was found since sequential coding pulses were available in the form of the CSP's from the coder. Fig. 16 shows the logic arrangement for the conversion process. It is significant to note that no intermediate buffer is required, resulting in minimum circuitry.

The remaining function of this component of the system is recording, which has already been described in detail.

System Operation

Operational flexibility is greatly enhanced by the modular construction of the components of the system. Flight testing of the smallest aircraft or larger missiles to the largest aircraft may be accomplished with ease simply by using those portions of the system required; that is, a smaller number of multiplexer modules. The flexibility of programming allows an operational versatility never before offered in airborne PCM systems.

If telemetering provisions are required in addition to or in place of tape recording, an FM transmitter may be connected to the serial output of the coder. A unique word for frame synchronization and alternating bit preceding each word for word synchronization can be provided. The resultant telemetric data conform to the standards set forth by the telemetry working group of the IRIG.

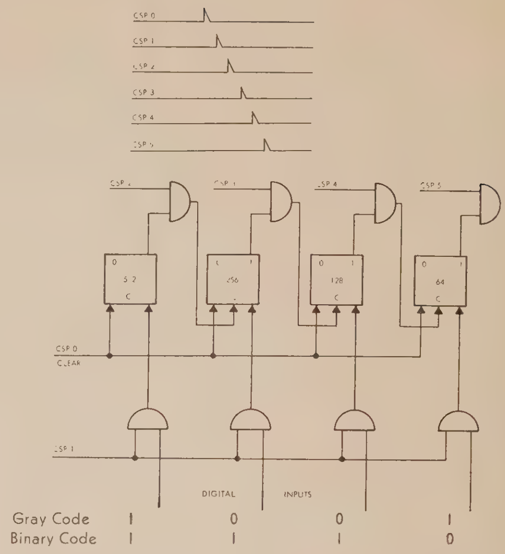

Fig. 16—Gray-to-binary converter. Block diagram.

Acknowledgment

Efforts were required of many of our associates i performance of system and component design. L. S McMillian, W. T. Eddins, W. A. Corry, G. E. Bradford and R. E. Marquand are a few who have made significant contributions to the success of the project.

Transistorized Motor Speed Controls for Satellite Tape Recorders*

MERWIN B. PICKOVER†

Summary—**The proposed paper discusses the problems arising in the design of an ac transistorized power supply for low power synchronous motors used in satellite recorders. It treats a current design for a specific satellite application, presents the design of the over-all system, and states alternate methods that can be used. The paper also discusses the over-all system parameters which must be considered in the choice of a hysteresis synchronous motor, the motor's operating frequency, and its characteristics.**

Also treated in the paper is a transistorized dc motor control used in a Signal Corps tape recorder. It discusses the servo loop used to accomplish the control of speed, and the accuracy that may be obtained. Diagrams of the exact circuit are presented and analyzed so that the reader may apply the technique to his future needs.

The relative advantages and disadvantages of the dc motor and ac synchronous motor in the low-power output range are discussed.

The system is designed to meet the environment of the satellite package. The emphasis is on a system requiring a minimum of power consumption and smallest possible size and weight, with no sacrifice of reliability or performance.

INTRODUCTION

SINCE size, weight, efficiency, and reliability are of primary importance in satellite circuitry, the government and private industry have been seeking a small transistorized speed control in order to maintain the speed of small dc and ac motors used for tape recorders and other motor applications.

DISCUSSION

At the present time the use of ac synchronous motors for extremely low power level may become impractical, due to the fact that a stable ac power supply and amplifiers are necessary for primary power, and the over-all efficiency of the system therefore suffers.

The inherent starting torque of the small dc motor is greater than an equivalent output hysteresis synchronous motor. This and its greater efficiency, are advantages that must be considered.

The use of mechanical speed governors to maintain a constant speed in the dc motors has been ruled out for many applications, due to the inherent vibration problems. The constant making and breaking of the governor contacts cause noise effects which must be suppressed.

At present four methods of control for small dc motors have been exploited. One is to place a dc generator at the end of the shaft whose output dc is now proportional to speed. By comparing this output to a reference (Zener diode), one can design circuitry to obtain the desired speed control.

An alternate method is to place another winding in the slots of the armature and bring out this ac voltage to slip rings. The frequency of the output voltage $f = np/120$ (n = speed in rpm and p = number of poles). Since this method requires another set of brushes, it is undesirable.

Still another method utilizes commutation ripple frequency which is proportional to speed. This method is not too successful at present, but it certainly should be explored.

The fourth method and the one most widely practiced is to place an ac generator at the end of the motor shaft whose output frequency is proportional to speed. A discriminator converts this change in frequency to a change in dc voltage, which is then applied to a dc amplifier to the motor input, or field winding.

DC Motor Speed Control

With the above considerations in mind a package of approximately three cubic inches, with a total power consumption of less than 100 mw for control purposes, was designed. Silicon transistors may be used throughout as a precaution for high temperature operation although the range of temperatures encountered is relatively small because of the design of the satellite package. The complete wiring diagram is illustrated in Fig. 1.

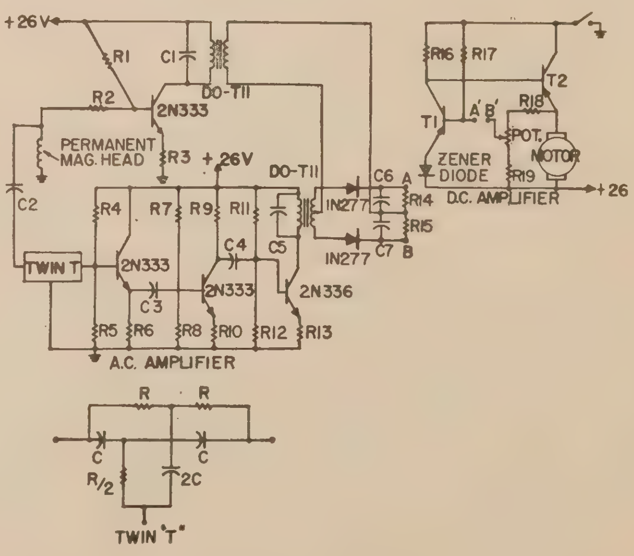

Fig. 1—DC motor supply.

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* Original manuscript received by the IRE, December 2, 1959.

† U. S. Army Signal Research and Development Lab., Fort Monmouth, N. J.

Principle of Operation: In order to control the speed of the dc motor a block diagram is illustrated in Fig. 2. The ac generator is mechanically driven by the dc motor. The output of the ac generator is fed into a sensing circuit. The construction of the ac generator is described later in the paper. A twin tee is used as the reference for frequency. The twin tee contains vitamin Q capacitors and one per cent resistors. These components were then selected so that the twin tee characteristics produced a minimum null at the desired frequency and a minimum drift of the null with temperature variations. Its characteristics are as shown in Fig. 3. An emitter follower was then placed across the output of the twin tee, in order to transform the relatively high impedance of the twin tee to a lower value. The twin tee output is then amplified by two stages of RC coupled amplifiers to give a 90° phase shift at the desired frequency and with additional gain. The output of the RC networks is now compared to the generator output, as illustrated by Fig. 4. This discriminator whose output has the sensitivity of one volt per 3 cps is linear to about ± 2 volts dc.

The dc amplifier maintains the nominal dc voltage necessary for operation. The discriminator output adds to or substracts from this nominal.

AC Generator: A problem that arose was the inability of permanent magnetic designers to produce a small magnet with the desired number of poles which would produce a relatively high frequency at a relatively low speed. The conclusion reached is that it is impossible to construct a magnetizer for this application.

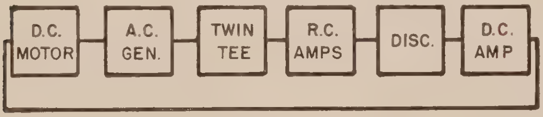

Fig. 2.

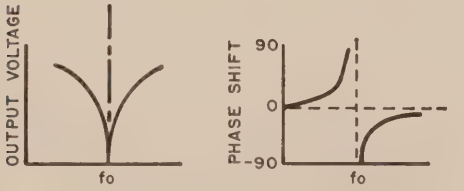

Fig. 3.

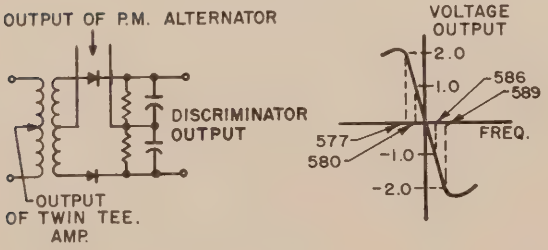

Fig. 4.

In order to overcome this a generator was constructed. This generator consists of a rotating magnesium wheel with permanent magnet inserts and a pick-up coil.

Permanent magnets: cunife;
Size of magnets: $\frac{1}{8}$ inch long, $\frac{1}{16}$ inch diameter;
Number of magnets or poles: 14;
Speed of dc motor or ac generator: 5000 rpm; frequency of output voltage $= np/120 = 583$ cps;
Pick-up coil of the generator: 12,000 T #43 HF wire;
DC resistance: 2000 ohms; 5000 ohms ac impedance;
Generator air gap: 0.010 ± 0.002;
Pick-up core material: silicon steel, U. S. Transformer #52 or equivalent;
Size of wheel: $\frac{7}{8}$ inch O.D.;
Frequency of twin tee: 583 cps;
Determined by: $\omega = 1/RC$, $\omega = 2\pi f$, $R = 13.3$ k, $c = 0.02$ μfd, $f = 583$ cps.

The value of R is usually chosen so that the twin tee does not load down the permanent magnet alternator winding, or an emitter follower may be necessary between the output of the alternator and the twin tee.

DC Amplifier: This circuit can best be explained by a typical example.

Given

1) nominal motor voltage 16 vdc,
2) maximum motor voltage 18 vdc,
3) minimum motor voltage 14 vdc,
5) nominal motor current 60 ma,
5) battery voltage 26 vdc.

Insert the motor in the circuit between the emitter of the *p-n-p* power transistor and +26 volts as shown in Fig. 1.

The nominal voltage at the emitter of the *p-n-p* power transistor is approximately +10 vdc.

The base of the *p-n-p* power transistor is approximately at +9.5 volts. That is also the potential at the collector of $T1$. $T1$ should be biased for 4.0-ma collector current. $R16$ can now be chosen as approximately 3000 ohms for steady-state conditions.

The potentiometer across the motor in conjunction with the Zener diode in the emitter circuit provides the desired dc level so that the output from the discriminator may be applied directly; it also provides a high impedance to the discriminator so that its loading effect may be neglected. A voltage more proportional to any discriminator output voltage, + or −, appears across $R16$ and therefore across the motor. The dc gain for the circuit shown is approximately one.

The Zener diode in the emitter is chosen to maintain a constant 14-volt drop and brings the base of $T1$ to approximately +11.5 volts. The potentiometer across the motor is set so that its arm is at this exact potential.

Therefore, points A' and B' are at the same dc potential and the detector may be impressed across A and B without difficulty.

The circuit is versatile. If the polarity of the 26 volts is reversed, a simple change of equivalent *n-p-n* transistors to replace the *p-n-p* transistors and a reversal of the Zener diode polarity will produce identical operation. The use of *p-n-p* transistors in the ac detector circuit gives similar results, with a change in battery voltage polarity.

Temperature compensation can be accomplished by a NTC for *R*18.

The accuracy of the speed control system is predicted in the following manner. It is necessary to know the change in motor voltage necessary to maintain a constant speed at all loads and ambient variations. By simply comparing this change in voltage to the change in detector dc voltage output, one can see what change in frequency to expect. If the detector output vs frequency is compensated for temperature variations, one can predict the change in speed that will occur. The present system is good for approximately one per cent total speed variation, for all ambients between −10°C to +60°C. It can be improved if the application presents itself.

AC Synchronous Motor Supply

If one is willing to sacrifice efficiency, quick starting, and size, the hysteresis or other synchronous motors have numerous advantages over the dc motor. Among them are longer life, no brush commutation noise and no brush dust problems. In order to produce the ac power, many considerations must be taken into account. The designer must choose a standard for frequency, a method of countdown, and a power amplifier. The choice of an operating frequency is usually governed by the synchronous motor manufacturers. At present 60 cps and 400 cps are commonly produced, although prototypes are available for 125 cps as well as for higher frequencies. The reference may be a crystal or tuning fork, or, if extreme accuracy is not required, a transistor oscillator may be used. When using a crystal, there is the problem of numerous countdown circuits and possibly magnetic memory cores for storage of pulses. When using a low-frequency tuning fork, countdown by four or eight is usually sufficient. In satellite application the over-all-system must be considered. If a tuning fork is used, it can be used for reference for other circuitry and also can be the reference for the synchronous power supply as in the case mentioned. The choice of a synchronous motor frequency presents the following problem. A 400-cps motor will be smaller in size and have a greater efficiency than an equivalent output 60-cps motor, but one must realize that this change in operating speed presents a mechanical problem of gearing or belt reduction in the recorder if low-speed operation is desired. The assumption is made that the number of poles is constant. The problem of the motor designer is to produce a small motor punching with many teeth, in order to keep the speed down to a reasonable operating point for a given frequency.

With these considerations in mind a system was designed to produce 125-cps power for a synchronous hysteresis motor for a tape recorder. (Refer to Fig. 5.) The tuning fork was manufactured by Philmon Laboratory. The synchronous motor was manufactured by Herbert C. Roters Inc., a recognized expert in the field of high efficiency hysteresis synchronous motors. All other circuitry was designed by the U. S. Army Signal Engineering Laboratory. It consists of a tuning fork and oscillator circuitry, two multivibrators used as countdown by four, a driver, and a push-pull amplifier. The output voltage to the synchronous motor was 12 volts rms ±2 per cent for ambients of −10°C to +60°C. Extreme accuracy in output voltage was not a requirement, since the motor will stay in synchronism for voltages between 11 to 15 volts with no degradation in performance. However, the higher voltage produces higher losses in the hysteresis motor, and actually a waste of power.

The multivibrator and push-pull output transistors were matched pairs. Temperature compensation can be accomplished by an NTC for resistor *R*28. The tuning fork oscillator and multivibrators required less than 100 mw of power, and the electrical efficiency of the driver amplifier and push-pull output was approximately 55 per cent. The transformer efficiency was slightly greater than 80 per cent. Class AB push-pull operation and the transformer efficiency were the limiting factors which controlled the over-all system efficiency.

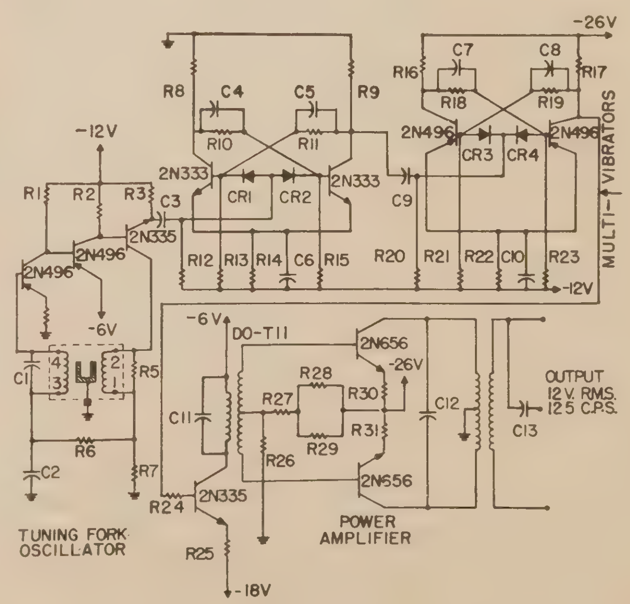

Fig. 5—AC synchronous motor supply.

CONCLUSION

The author has presented two of the circuits used for the control of the speed of small motors. In particular, the controls have been used for a tape recorder, record cycle, and playback cycle. The type of control lends itself to other satellite application, when the control of the speed of motors at all environments is necessary. Most of the components have been selected. All transistor characteristics were observed on a curve-tracer to insure the reliability of the package. As stated above, certain transistors were matched pairs, so that their relative changes in gain vs temperatures would be minimized. If one is striving for simplicity of circuitry, minimum power consumption, minimum size, and reliability, the above procedure must be observed.

ACKNOWLEDGMENT

The author wishes to express his appreciation to Dr. R. A. Hanel, formerly of the U. S. Army Signal Research and Development Laboratory, now affiliated with the National Aeronautics and Space Administration, for his technical contribution during initial design of the system.

Checkout and Countdown of the Larger Space Probe Missiles*

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Summary—**While it is obvious that missiles for different space programs carry widely different electronic equipment, it is not so apparent that missiles on the same program may carry just as wide a variety of equipment. Checkout and countdown equipment must be versatile, not only because of the variety of electronic airborne equipment, but because of the special needs of research and development programs and for follow-on programs. Moreover, the equipment must offer a high level of performance reliability, so that the operator may concentrate on firing the missile.**

The design of the centrally programmed checkout and countdown set presented here incorporates digital techniques. The punched tape supplies those commands that are subject to frequent change, such as GO—NO-GO limits—and mode and range commands for the parameter converters. Manual operation and visual evaluation are possible. These provisions also raise follow-on utility.

Use of the design criteria of self-verification at every step, positive malfunction localization, standby verification and design simplicity yield a design with a high level of performance reliability.

INTRODUCTION

THE missiles of today, as they probe deeper into space, are forced to carry a greater and greater variety of electronic and research equipment, necessary because we know so little about the phenomena that occur in outer space.

The stages of the missile also undergo changes in the electronic configuration, from flight to flight. Each change, however minor, usually calls for a similar one in the support equipment. A change in autopilot mixing ratios or gain settings requires a corresponding change in the checkout equipment. More often than not, the change is of greater magnitude and expense than the original change in the missile. Even so simple a change as the tolerance of a particular parameter of the missile requires a corresponding change in the GO—NO-GO testing limits.

This presents a never-ending series of new problems to the launch crew. To make the situation more interesting, the crew does not have all the time in the world to make changes. With the next flight date only two weeks away, they can hardly be expected to spend their time reworking the support equipment. Obviously, the design must be such that changes in it will not impede the steady flight-to-flight schedule of testing.

On top of all these requirements, performance reliability is required of the checkout and countdown equipment. These two requirements are of paramount importance: 1) performance reliability and 2) versatility. The following discussion develops these requirements more fully and presents a block diagram solution to them for the checkout and countdown of a typical deep space probe missile.

PERFORMANCE RELIABILITY

The checkout equipment designs of several years ago were predominantly manual in nature, consisting of standard laboratory meters, oscilloscopes and other familiar equipment. Being manual, they were quite reliable. Certain problems were presented, however, usually involving personnel training and speed. Gradually, the equipment evolved into semi-automatic designs. The evolution was encouraged on the part of the military by

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* Original manuscript received by the IRE, November 23, 1959.

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the allocation of sums of money for ground support research and development.

In converting from the manual to the semi-automatic designs, it was desirable that the high reliability level of the manual equipment be preserved. This is best stated in a rather paradoxical fashion; *i.e.*, the countdown reliability of the support equipment should be greater than that of the missile.

Gradually a more specific term, "performance reliability," evolved. Performance reliability means that, considering the system as a whole, the support equipment must always correctly evaluate the situation for the operator. This characteristic quickly instills a high level of confidence in the equipment.

Fig. 1 explains the characteristic more fully, showing what it is and how it is secured. Follow the path of a typical signal coming from a missile and arriving at the comparator. It goes first through a self-test relay contact, then through a programmer and finally into a signal conditioner, which conditions the signal to a common level so that a single comparator can be used for the majority of the tests.

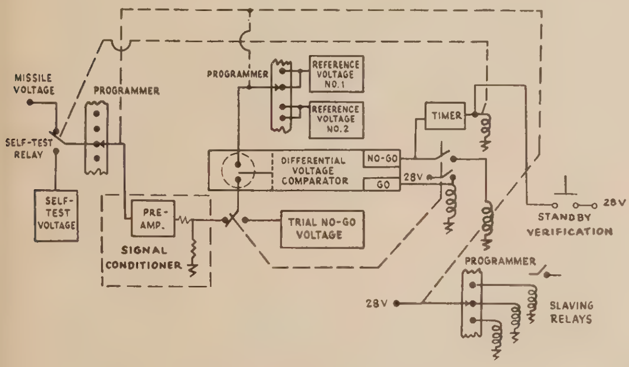

Fig. 1—General method of automatic analog testing.

The programmer, shown as a simple stepping switch, also connects a proper reference into the other side of the comparator. The one shown is a fixed-difference comparator such that, if the difference between the conditioned signal and the reference value is less than a predesigned amount, the comparator will register a GO condition.

Assume, for purposes of this discussion, that this condition obtains and that the comparator is registering a GO condition. If asked to make a guess, the reader would assume that the next operation would be that of the programmer advancing to set up the next step. Such is not the case here. Instead, the equipment temporarily memorizes the apparent fact of the GO condition and sets it aside, because it is not certain at the moment whether the GO condition is bona fide or the result of the combination of a faulty missile and malfunctioning checkout equipment.

The next operation is that of programming a trial NO-GO voltage into the comparator. Now, if the comparator can be made to recognize a GO condition, which has just occurred, and likewise a NO-GO condition, occurring at the moment, then the comparator decision has been verified. The GO condition previously received is a bona fide GO condition and is recognized as such. At this point, a signal is flashed to the programmer to advance to the next step. This process is called self-verification at every step. It represents the first part of certain design criteria which give this method of testing a very high performance reliability.

If, on a particular test, a sustained NO-GO condition is registered by the comparator, a timer is energized (see Fig. 1). After a short interval, the timer activates a self-test relay. The relay temporarily disconnects the missile response and in place of it connects a design-center response. If the checkout equipment is operating properly, it will recognize the design-center value as a GO condition. This response, by means of circuitry not shown, is used to light a lamp or other signalling device to indicate that the trouble lies within the missile, since it is not in the checkout equipment.

If the comparator gives a NO-GO condition upon evaluation of the design-center value, the trouble lies within the checkout equipment. An appropriate signalling device is energized to signify the fact. This process is positive malfunction localization, a part of the normal functioning of the equipment. It is the second of the design criteria which must be used to give performance reliability.

A further requirement is the certain knowledge that the equipment is capable of making a countdown before a scheduled countdown takes place. It is necessary to use the equipment on a standby basis and verify that it is operating properly. This is done in Fig. 1 by closing a standby verification switch to activate all of the self-test relays and by allowing the checkout equipment to evaluate the design-center values throughout. Completion of the sequence verifies that it is operating properly at all steps. Automatic standby verification is the third criterion for performance reliability.

The fourth criterion states that the first three must be incorporated into the basic design with addition of very little extra equipment. Obviously, this is a criterion; to do otherwise would cause the over-all reliability to go down rather than up. Examination of Fig. 1 shows that this last criterion has indeed been met. The functional modules shown are present in one form or another in any semi-automatic checkout design. The difference lies in the logical way the modules are used.

VERSATILITY

Several kinds of versatility are required. One is electronic versatility commensurate with the variety of electrical and electronic gear. The first flight may carry a standard guidance system for coordination purposes. A pre-programmed autopilot may be used as an interim model. On the second flight, the standard system may be used to guide the missile. Certain new communications equipment may be aboard. The same autopilot as before is used, but now the gains, tolerances, and mixing ratios are different. These factors all add up to the requirement that checkout equipment designs incorporate a degree of versatility equal to that of the space probe missiles themselves.

Research and development *use* is another kind of required versatility. Lunar shots require timing to within minutes. Several weeks may pass before conditions are favorable again, so it is mandatory to launch the missile on time. A typical countdown is started hours in advance, so that lift-off can occur on schedule. This requirement means that in the countdown equipment there must be a capability to stop and go, or to wait while certain tasks are performed.

Not only must there be an automatic capability for such a program, but when necessary, a completely manual checkout and countdown capability. The operator must have visual readout at the console for all tests. He must also be provided with a recording capability so that the value of each test may be recorded and identified for later use by safety and reliability groups.

Follow-on versatility is a requirement that has recently come to light. Fifteen years ago it was hardly considered necessary, or even possible, that the support equipment be useful for later programs, possibly because the equipment was not so costly at that time. Today's space programs, however, are vast and complicated. The necessary checkout and countdown equipment is so expensive that it must be reasonably useful for succeeding programs.

DIGITAL CHECKOUT AND COUNTDOWN SET

Fig. 2 shows the block diagram of a centrally-programmed digital checkout and countdown set as a solution to the requirements for performance reliability and for the various kinds of versatility. It is presented in system fashion only, since this level of presentation is best suited to show just how such a set meets the requirements. The system details are too many to permit a lucid explanation of the operation by referring to it

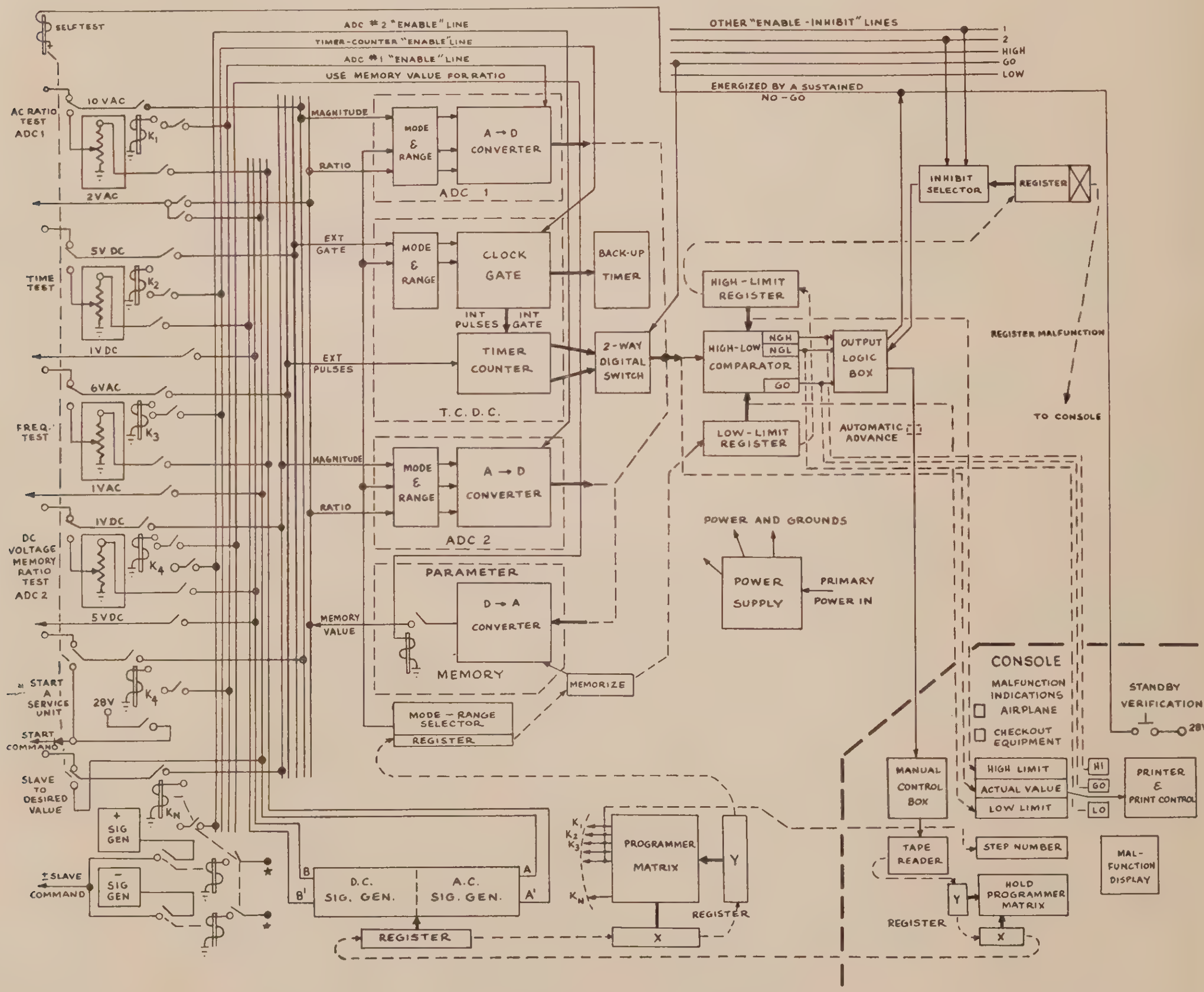
SELF TEST
ADC #2 "ENABLE" LINE
TIMER-COUNTER "ENABLE" LINE
ADC #1 "ENABLE" LINE
USE MEMORY VALUE FOR RATIO
OTHER "ENABLE-INHIBIT" LINES
1
2
HIGH
GO
LOW
ENERGIZED BY A SUSTAINED NO-GO
10 VAC
AC RATIO TEST ADC 1
K1
2 VAC
5V DC
TIME TEST
K2
1V DC
6VAC
FREQ. TEST
K3
1VAC
1VDC
DC VOLTAGE MEMORY RATIO TEST ADC 2
K4
5VDC
START A SERVICE UNIT
28V
K4
START COMMAND
SLAVE TO DESIRED VALUE
KN
+ SIG GEN
− SIG GEN
±SLAVE COMMAND
MAGNITUDE
RATIO
MODE & RANGE
A→D CONVERTER
ADC 1
EXT GATE
CLOCK GATE
INT PULSES
INT GATE
BACK-UP TIMER
EXT PULSES
TIMER COUNTER
T.C.D.C.
2-WAY DIGITAL SWITCH
MAGNITUDE
RATIO
MODE & RANGE
A→D CONVERTER
ADC 2
PARAMETER
MEMORY VALUE
D→A CONVERTER
MEMORY
MEMORIZE
MODE-RANGE SELECTOR
REGISTER
INHIBIT SELECTOR
REGISTER
HIGH-LIMIT REGISTER
HIGH-LOW COMPARATOR
NGH
NGL
GO
OUTPUT LOGIC BOX
LOW-LIMIT REGISTER
AUTOMATIC ADVANCE
REGISTER MALFUNCTION
TO CONSOLE
POWER AND GROUNDS
POWER SUPPLY
PRIMARY POWER IN
CONSOLE
MALFUNCTION INDICATIONS
AIRPLANE
CHECKOUT EQUIPMENT
STANDBY VERIFICATION
28V
HIGH LIMIT
ACTUAL VALUE
LOW LIMIT
HI
GO
LO
PRINTER & PRINT CONTROL
MANUAL CONTROL BOX
TAPE READER
STEP NUMBER
HOLD PROGRAMMER MATRIX
Y
X
REGISTER
MAL-FUNCTION DISPLAY
K1
K2
K3
KN
PROGRAMMER MATRIX
Y
X
REGISTER
B
B'
D.C. SIG. GEN.
A.C. SIG. GEN.
A
A'
REGISTER

Fig. 2—A centrally-programmed digital checkout and countdown set. Star denotes 28 volts from low and high *enable-inhibit* lines.

directly. To explain the operation simply, portions of it are broken out in succeeding diagrams.

Fig. 3 shows the heart of the checkout and countdown unit, a comparator with high and low limit registers, an output logic box, two analog-to-digital converters with proper mode and range units connected to them, a timer-counter with proper mode and range unit and a parameter memory unit.

The analog-to-digital converter transforms the various missile analog parameters to a corresponding digital number. The comparator compares this digital number with the digital numbers stored in the lower- and upper-limit registers. If the missile value lies between these limits, the comparator registers a GO condition. The digital resolution of this system is 2^{11} bits; in other words, 2048 parts for a full-scale reading, with one bit on the basic range equal to 1 mv dc. A dual (high-low) type of comparator and the upper- and lower-limit registers solve the problem of changes of tolerance and nominal level, providing part of the answer to the requirement for electronic versatility.

The mode and range boxes for both analog-to-digital converters (ADC) and the timer-counter-to-digital converter (TCDC) are remotely programmed from an easily-changed tape, giving versatility for various modes and ranges. The ADC can be used in a dc mode with ranges of 0 to 1, 5, 10, 20, 50, 100, and so on. It is also used in the ac mode with the same ranges. In the ratio mode, two voltages are programmed into the converter, and the value converted is the ratio of the one to the other.

The timer-counter utilizes a basic capability for counting pulses to measure several types of parameters. When measuring external time, the device counts pulses supplied by the internal clock during the gated time interval bounded by $T=0$ and the $T=t$ arrival of the external timing signal. An external frequency measurement is taken by counting external pulses for a precise time interval gated by the internal clock.

Period and remaining related parameters are similarly handled, with ranges sufficient to give a high counting accuracy, even for very large numbers. The output of

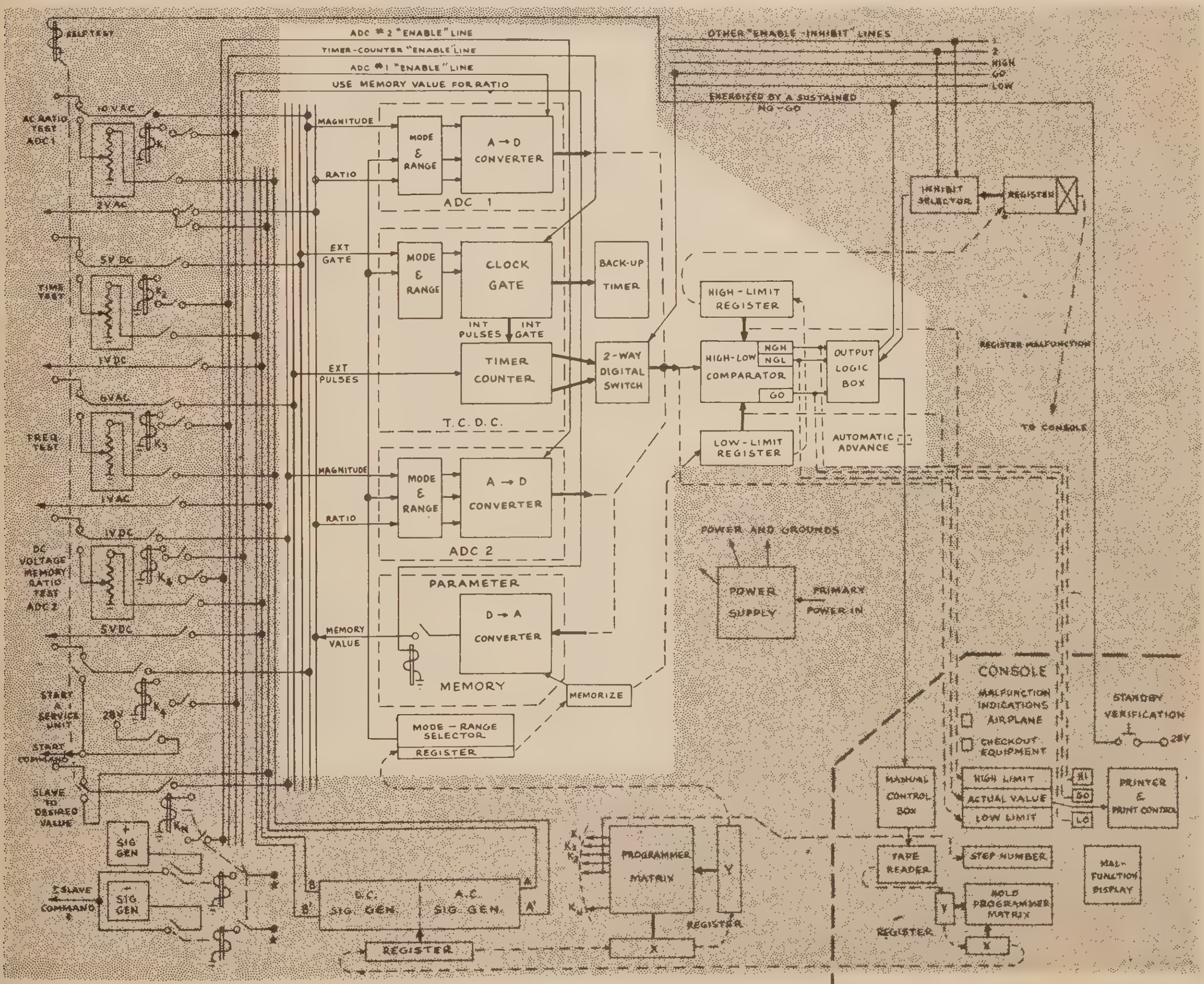
SELF TEST
ADC #2 "ENABLE" LINE
TIMER-COUNTER "ENABLE" LINE
ADC #1 "ENABLE" LINE
USE MEMORY VALUE FOR RATIO
OTHER "ENABLE-INHIBIT" LINES
1
2
HIGH
GO
LOW
ENERGIZED BY A SUSTAINED NO-GO
10 VAC
AC RATIO TEST ADC 1
K_1
2 VAC
5 V DC
TIME TEST
K_2
1 VDC
6 VAC
FREQ TEST
K_3
1 VAC
1 VDC
DC VOLTAGE MEMORY RATIO TEST ADC 2
K_4
5 VDC
START A SERVICE UNIT
28 V
START COMMAND
SLAVE TO DESIRED VALUE
K_N
+ SIG GEN
SIG GEN
SLAVE COMMAND
MAGNITUDE
RATIO
MODE & RANGE
A → D CONVERTER
ADC 1
EXT GATE
MODE & RANGE
CLOCK GATE
BACK-UP TIMER
INT PULSES
INT GATE
EXT PULSES
TIMER COUNTER
T. C. D. C.
2-WAY DIGITAL SWITCH
MAGNITUDE
RATIO
MODE & RANGE
A → D CONVERTER
ADC 2
PARAMETER
D → A CONVERTER
MEMORY VALUE
MEMORY
MEMORIZE
MODE – RANGE SELECTOR
REGISTER
HIGH-LIMIT REGISTER
HIGH-LOW COMPARATOR
NGH
NGL
GO
OUTPUT LOGIC BOX
LOW-LIMIT REGISTER
AUTOMATIC ADVANCE
INHIBIT SELECTOR
REGISTER
REGISTER MALFUNCTION
TO CONSOLE
POWER AND GROUNDS
POWER SUPPLY
PRIMARY POWER IN
CONSOLE
MALFUNCTION INDICATIONS
AIRPLANE
CHECKOUT EQUIPMENT
STANDBY VERIFICATION
28V
MANUAL CONTROL BOX
HIGH LIMIT
ACTUAL VALUE
LOW LIMIT
HI
GO
LO
PRINTER & PRINT CONTROL
TAPE READER
STEP NUMBER
MAL-FUNCTION DISPLAY
HOLD PROGRAMMER MATRIX
Y
X
REGISTER
K_1
K_2
K_3
K_N
PROGRAMMER MATRIX
Y
REGISTER
X
B
B'
D.C. SIG. GEN.
A.C. SIG. GEN.
A
A'
REGISTER

Fig. 3—A centrally-programmed digital checkout and countdown set; converters, comparator, parameter memory, logic box. Star denotes 28 volts from low and high *enable-inhibit* lines.

the counter is 2^{22} digital bits. Use of the two-way digital switch allows the 11-bit comparator to evaluate a large number by evaluating first one set of lines, then the other set.

Each time the ADC-Comparator combination is used, GO and NO-GO conditions are evaluated for purposes of self-verification of the combination, for reasons identical to those noted in the explanation of Fig. 1. This is the implementation of one of the design criteria for performance reliability. A similar process of self-verification is employed when the timer-counter-comparator combination is used.

The comparator itself does not make any decisions other than LOW NO-GO, GO, or HIGH NO-GO. It supplies these outputs to the logic box, a device which decides upon the basis of predetermined logic whether the result of a test is a bona fide GO or NO-GO. If the result is GO, an AUTOMATIC ADVANCE command is given.

If the result of a particular test is a bona fide NO-GO, the logic box activates a self-test relay for the reasons explained for Fig. 1. This action implements the second criterion for performance reliability. Design-center values are automatically provided by a means to be explained in Fig. 5.

The parameter memory in Fig. 3 continually converts all digital numbers fed to the comparator into corresponding analog values. When the value of a particular parameter is to be retained for later use, a MEMORIZE command is given to the device, and the value is held indefinitely. Feeding this value into the ratio side of either ADC permits one test to be compared with another.

It is worthy of note that the parameters which can thus be compared are not limited to like dimensions, such as voltage to voltage. Just as easily, time can be compared to voltage, frequency to current, and resistance to period. Suitable ranges exist for the parameter memory, of course. They are set up by proper remote programming of the mode-range selector box, which performs a similar function for the other converters.

All the converters are permanently connected into the comparator. Each converter exists in one or the other of two states, the *inhibited* state or the *enabled* state. Only one at a time is used to feed digital information into the comparator; the remaining units are in a compatible, quiescent, inhibited state. This feature eliminates the need for a selector switch at the input to the comparator. *Enable* lines are brought out from each unit and are externally programmed to put the unit into the *enabled* state.

Various choices of ranges are to be considered. Some groups hold that decimals or powers of ten are the only ranges that should be used in a digital system. The reasoning here is that any general-purpose remote readout then can read directly in terms of the actual parameter, rather than in terms of some conditioned value of it. But the powers of ten will allow ranges of 0 to 1 volt, 0 to 10, 0 to 100, etc., only. The basic resolution is good at the maximum value of any of these ranges or just slightly below it, while at values immediately above the range it is poor.

For example, consider a missile parameter value of 9.9 volts. On the 0- to 10-volt range, the value is resolved into 999 bits—a figure adequate for most problems of tolerance. However, if the value were 11 volts, the 0- to 10-volt range would be useless and the 0- to 100-volt scale would be required. The value on this scale, instead of being divided into 1100 bits, would be divided into 110 bits out of a possible maximum of 1000 bits for 100 volts.

This situation is particularly unfortunate if a missile parameter of 11 volts must be evaluated to a tolerance of ±2 per cent, or 0.22 volt, to cite a typical problem. On the 100-volt scale, the converter has a basic resolution of 0.1 volt per bit; it would produce digital numbers corresponding to 10.7, 10.8, 10.9, 11.0, 11.1, 11.2, 11.3 volts and so on. A glance shows that the tolerance band of ±0.22 volt is resolved, or divided, into only four digital bits.

It follows that, with the best performance obtainable from a digital comparator equal to an "uncertainty" of ±1 bit, such a measurement would be unsatisfactory since the digital system is "consuming" half of the missile tolerance band. The use of powers of ten as the only choice for ranges leaves some fairly wide gaps in the resolution and evaluation capability of the countdown equipment. Fig. 4 shows how this occurs and how to alleviate the situation.

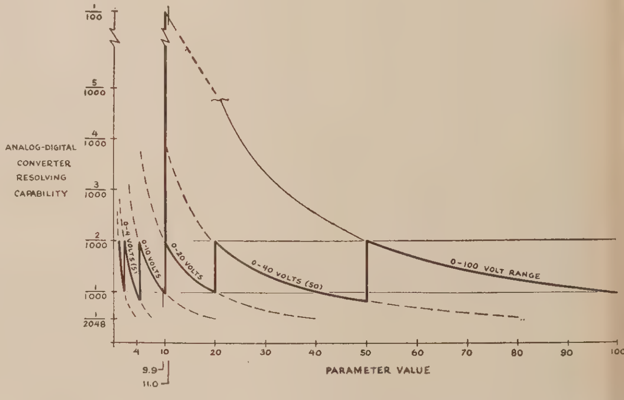

Fig. 4—Choice of multiple ranges to preserve basic evaluation accuracy. Titles for each range are *nominal* titles; for example, the 0–10-volt range may be used to 20.48 volts.

Remember that the basic accuracy and resolution of any countdown or comparison equipment should be one order of magnitude better than the closest tolerance required for any missile parameter. With the resolution equal to 1 part per 2048 for any maximum range value, it is reasonable to use as many ranges as necessary to help preserve this capability across all ranges. In this system, use is made of the basic powers of ten, plus a number of intermediate ranges. The entire set is 0 to 1, 0 to 2, 0 to 4, 0 to 10, 0 to 20, 0 to 40, 0 to 100, etc., with the 4- and 40-volt ranges used to 5 and 50 volts.

Fig. 4 shows that the worst resolution with this set of ranges is only 2 parts per thousand. To be sure, the remote readout on ranges other than the powers of ten is a readout in terms of a conditioned value rather than of the actual value. However, since the upper and lower limits are also read out in terms of the conditioned value, it is the opinion of some that visual readout of conditioned values does not present any particularly great psychological problem.

Fig. 5 shows a number of relays along one side of the diagram. One is required for each test. It connects the proper signal to the missile, connects the response from the missile to the proper signal conditioner, activates the design-center value, and supplies an *enable* command to the proper evaluator. Several of the more commonly required types of tests are shown, the most interesting one of which is the slaving relay. In this instance, the checkout and countdown unit is used as a servomechanism to accomplish such tasks as torquing a gyroscope to a desired value and rotating a tracking antenna to a position according to the numbers set into the upper- and lower-limit registers.

On the lower side is shown a random sequence programmer matrix. It accepts a digital number $K_1 \cdots K_n$ in any sequence and energizes the proper relay $K_1 \cdots K_n$. Tests or groups of tests which are not required for a particular countdown are not programmed. Additional flexibility is inherent in the fact that the racks and chassis containing relays $K_1 \cdots K_n$ are wired in a standardized fashion. The use of a new subsystem in a missile calls for a new countdown chassis with relays properly connected.

The standard signal generators are digitally programmable voltage units. According to the number in the register, they supply both an ac signal and a dc signal to line A-B. They supply ac and dc signals, which are sev-

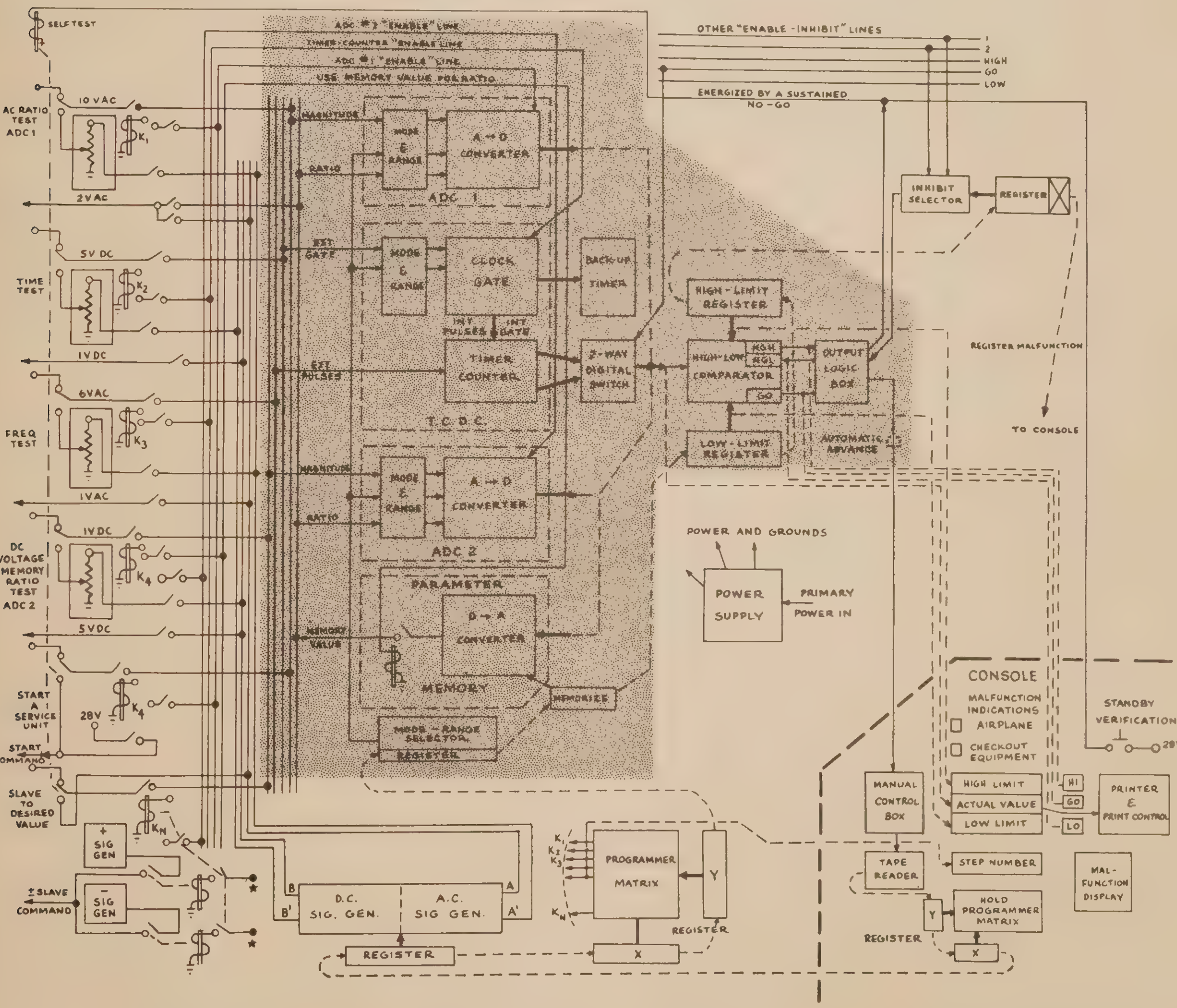
SELF TEST
AC RATIO TEST ADC 1
10 VAC
K1
2 VAC
5 V DC
TIME TEST
K2
1 V DC
6 VAC
FREQ TEST
K3
1 VAC
1 V DC
DC VOLTAGE MEMORY RATIO TEST ADC 2
K4
5 V DC
START A SERVICE UNIT
28V
K4
START COMMAND
SLAVE TO DESIRED VALUE
KN
+ SIG GEN
± SLAVE COMMAND
SIG GEN
ADC #2 "ENABLE" LINE
TIMER-COUNTER "ENABLE" LINE
ADC #1 "ENABLE" LINE
USE MEMORY VALUE FOR RATIO
MAGNITUDE
RATIO
MODE & RANGE
A → D CONVERTER
ADC 1
EXT GATE
MODE & RANGE
CLOCK GATE
BACK-UP TIMER
INT PULSES
INT GATE
EXT PULSES
TIMER COUNTER
2-WAY DIGITAL SWITCH
T.C.D.C.
MAGNITUDE
MODE & RANGE
A → D CONVERTER
RATIO
ADC 2
PARAMETER
MEMORY VALUE
D → A CONVERTER
MEMORY
MEMORIZE
MODE-RANGE SELECTOR
REGISTER
OTHER "ENABLE-INHIBIT" LINES
1
2
HIGH
GO
LOW
ENERGIZED BY A SUSTAINED NO-GO
INHIBIT SELECTOR
REGISTER
HIGH-LIMIT REGISTER
HIGH-LOW COMPARATOR
HIGH
HGL
GO
OUTPUT LOGIC BOX
LOW-LIMIT REGISTER
AUTOMATIC ADVANCE
REGISTER MALFUNCTION
TO CONSOLE
POWER AND GROUNDS
POWER SUPPLY
PRIMARY POWER IN
CONSOLE
MALFUNCTION INDICATIONS
AIRPLANE
CHECKOUT EQUIPMENT
STANDBY VERIFICATION
28V
MANUAL CONTROL BOX
HIGH LIMIT
ACTUAL VALUE
LOW LIMIT
HI
GO
LO
PRINTER & PRINT CONTROL
TAPE READER
STEP NUMBER
MAL-FUNCTION DISPLAY
Y
HOLD PROGRAMMER MATRIX
REGISTER
X
K1
K2
K3
KN
PROGRAMMER MATRIX
Y
REGISTER
X
B
B'
D.C. SIG. GEN.
A.C. SIG GEN.
A
A'
REGISTER

Fig. 5—A centrally-programmed digital checkout and countdown set; test relays, programmer, signal generators, console. Star denotes 28 volts from low and high *enable-inhibit* lines.

eral times greater, to lines A'-B'. The signals on lines A and B are picked up by the various relay contacts and routed to the proper parts of the missile system. The signals on lines A'-B' provide design-center values for malfunction localization.

Should a malfunction occur, the checkout equipment will positively isolate the malfunction to the missile or to the checkout and countdown equipment. Careful control of the sequence in which tests are performed permits location of the trouble within the missile to a particular malfunctioning unit without additional tests or subroutines.

The console houses the remaining portions of the set needed for performance reliability and flexibility. The operator uses the manual control panel to disable the AUTOMATIC ADVANCE command whenever it is necessary to proceed on a manual basis. The four arabic readouts of step number, low limit, actual value, and high limit afford him adequate information to evaluate visually the test results. A MANUAL ADVANCE push button is provided on the manual control panel.

Monitoring panels are not shown. Each parameter is displayed on a relay meter with adjustable high- and low-limit switches. These switches can be connected in any combination of AND and OR logic necessary, with the total monitoring function serving as an INHIBIT function to the AUTOMATIC ADVANCE signal and energizing a suitable alarm.

The hold programmer serves two purposes. One is that of scheduling a HOLD in the countdown while a planned manual routine is being carried out. Each HOLD of this type illuminates proper instructions on the console, such as PERFORM MANUAL ROUTINE A. The operator does not proceed until he receives verification over the communication system that the routine has been properly carried out.

The other purpose served by the hold programmer is that of coordinating the primary checkout and countdown set with auxiliary equipment. When sequencing between two equipments is required, a coordination hold is programmed. The set waits until a signal arrives from the other equipment, signifying that the desired test has been performed; then it proceeds. The programmer is of the random sequence type; it can be scheduled during any portion of the countdown.

The tape reader provides all the information needed in the various registers throughout the system. The tape itself may be of any type; aluminum-backed mylar is often used. A readout speed of 100 to 200 frames per second will permit an over-all rate, for the set, of three to four tests per second.

The malfunction display is a card prepared for each flight, listing by step numbers the particular portion of the missile being tested. The printer records the pertinent data of each test with the step number. A print control permits the printer operation to be inhibited.

As in Fig. 1, standby verification is provided by a manual switch to energize the self-test relays. The set may be installed in several configurations. In a typical launch pad, the bulk of the equipment can be installed in a nearby sheltered area, with the console in a safe area several hundred feet away. Lead-length problems inevitably appear on some of the missile high-impedance test points. The two converters are provided so that, if necessary, one can be installed immediately adjacent to the missile.

CONCLUSION

The set is versatile. Technical changes can be accommodated by preparing a new tape. The capabilities for manual operation, for programming holds as desired, and for making visual evaluations on all tests are adequate for research and development purposes. The set can be installed in several configurations. The basic programming, evaluation, readout, and recording portions are readily usable for follow-on programs.

Performance reliability is inherently high in this centrally-programmed digital checkout and countdown set. Test results are verified immediately. Malfunction localization is positive. Standby verification is simple. All three criteria are fulfilled in a simple manner. Military equipment embodying these criteria has already been designed; use of it instills a high level of confidence in the operator.

Radiation Instrumentation Electronics for the Pioneers III and IV Space Probes*

CONRAD S. JOSIAS†, MEMBER, IRE

Summary—One of the devices carried aboard lunar payloads, Pioneer III and Pioneer IV, was a radiation measurement instrument. Its purpose was to detect and process information on particle flux rates encountered along the nominal cis-lunar trajectory to be followed by those payloads.

Radiation data were collected by two different Geiger-Mueller tubes. One tube registered particle counts and the resultant accumulation was stored in a 17-stage scaler. The other tube provided average pulse current that was a compressed function of the counting rate. This current was fed to a resistor and the voltage thus formed was transferred to a telemetering subcarrier oscillator by way of a stable dc amplifier.

The electronics discussed in this paper fall into three groups: 1) dc amplifier for the analog experiment, 3) high-voltage circuitry for the detectors, 3) digital circuitry for the counting experiment.

Details of the encoding system, which permits a large dynamic range of counting rates to be clearly presented on a single subcarrier, are also discussed.

INTRODUCTION

WHEN Pioneer IV successfully escaped the earth's gravitational pull to pass in the vicinity of the moon, it carried an instrument intended to measure the radiation intensity along a nominal trajectory between the earth and the moon and possibly beyond. Its Geiger-Mueller detectors registered charged particles having energies above certain thresholds determined by detector wall thicknesses. The detectors were also capable of low-efficiency gamma radiation measurements. Cognizance for this radiation experiment was held by Van Allen of the State University of Iowa (SUI), whose responsibility entailed definition of the experiment, calibration of the flight packages and interpretation of flight results.[1,2] In addition, he specified the radiation detectors for the experiment and outlined, in general terms, the type of system to be used with the detectors. The design and construction of the electronic "radiation" package containing counters, pulse circuitry, a high-voltage supply, dc amplifiers, and data coding and compression devices were done at the Jet Propulsion Laboratory (JPL), California Institute of Technology, Pasadena, California.[3]

An earlier attempt was made by the Army Ballistic Missile Agency (ABMA) and JPL to inject a payload into a lunar trajectory. This first cone-shaped assembly, Pioneer III, did not achieve escape velocity and as a result soared to an altitude of 63,500 miles before returning to the earth. Ironically, measurement of the earth-bound radiation fields was more complete than if the probe had achieved its lunar objective. Extensive data were compiled not only on the outward leg of the payload trajectory but also on the return phase. The results of this experiment indicated for the first time the depth and contour of the partially explored radiation belt. Two Geiger-Mueller tubes were used aboard Pioneer III as radiation detectors. One of the tubes was used as a standard particle counter whereas the other tube was used as an indicator of average Geiger-pulse current. A package of nearly identical design was flown aboard Pioneer IV. The only modification consisted of 4 grams/cm^2 of lead shielding around the current averaging Geiger tube for the purpose of providing additional radiation energy data.

OUTLINE OF CIRCUIT OPERATION

As indicated in the block diagram of Fig. 1, the radia-

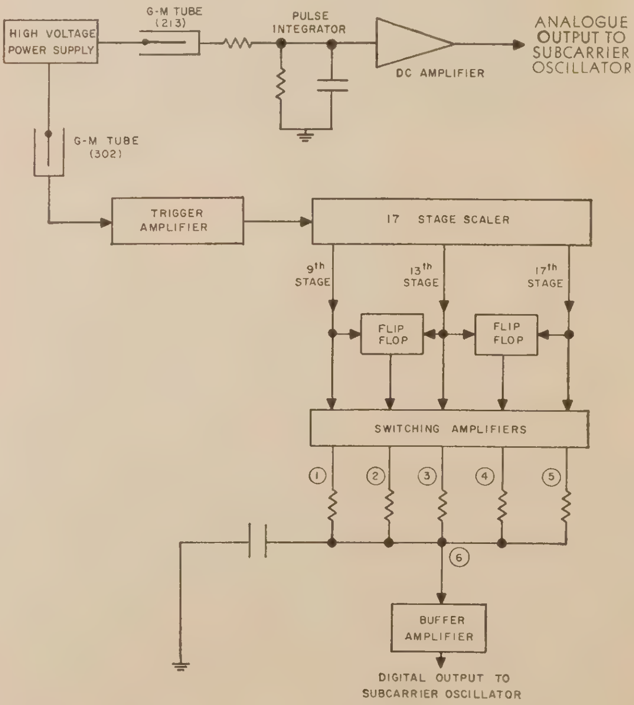

Fig. 1—Block diagram of radiation experiment.

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* Original manuscript received by the IRE, December 2, 1959. This paper presents the results of one phase of research carried out at the Jet Propulsion Lab., Calif. Inst. Tech., under Contract No. NASw-6, sponsored by the Natl. Aeronautics and Space Admin.

† Jet Propulsion Lab., California Institute of Technology, Pasadena, Calif.

[1] J. A. Van Allen and L. A. Frank, "Radiation around the earth to a radial distance of 107,400 km," *Nature*, vol. 183, pp. 430–434; February 14, 1959.

[2] J. A. Van Allen and L. A. Frank, "Radiation measurements to 658,300 km, with Pioneer IV," *Nature*, vol. 184, pp. 219–224; July 25, 1959.

[3] C. S. Josias, "Pioneer's radiation detection instrument," *Astronautics*, vol. 4, pp. 32–33, 114–115; July, 1959.

tion experiment was divided into two measurements. In one measurement, pulses obtained from an Anton Type 302 Halogen-quenched tube are processed through a trigger amplifier and then counted in a scaler from which multiple digital outputs are mixed and fed to a subcarrier oscillator. Current pulses obtained from an Anton Type 213 Geiger tube are integrated in an RC filter and the average voltage thus formed is fed to a second subcarrier oscillator through a high-input-impedance unity-voltage-gain power amplifier. The resultant voltage change at the output of the amplifier or frequency shift of the subcarrier oscillator is a compressed analog representation of the radiation intensity. The circuitry just described consumed 250 milliwatts of power at nominal battery voltage (7.2 volts) and is contained in the assembly shown in Fig. 2.

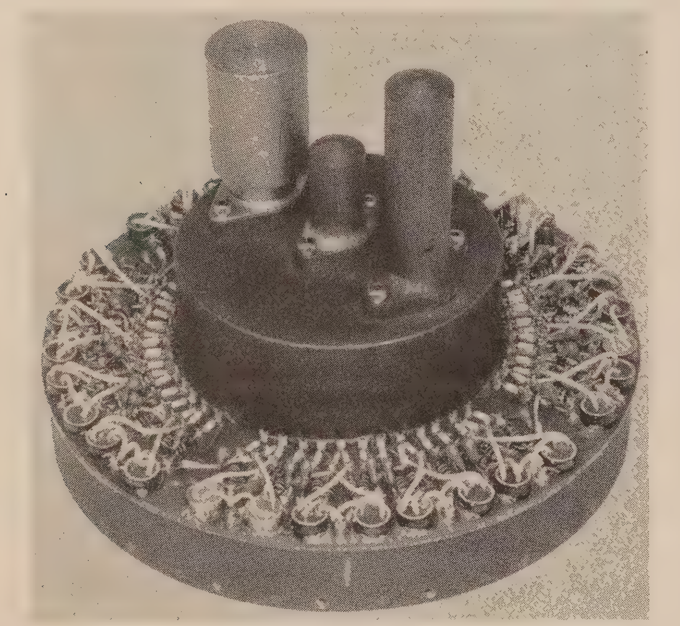


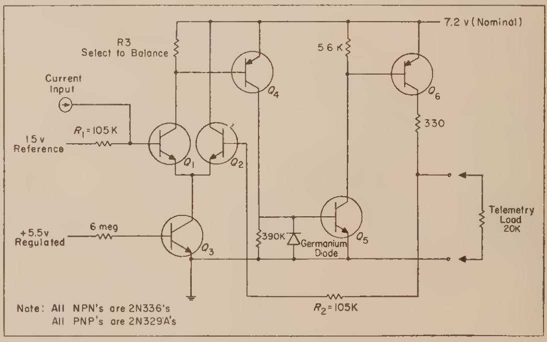
Fig. 2—Pioneer IV subassembly, top view.

DC Amplifier

One of the occupational hazards confronting the modern scientific experimenter is the continual materialization of information which often makes even new systems obsolescent. Information of this sort did indeed materialize, literally out of thin air (or space), late in the instrument development phase. Results of radiation experiments conducted by Van Allen in the Explorer IV earth satellite were observed a few weeks before scheduled delivery of the prototype radiation subassembly to the JPL Payload Group. The radiation intensity at apogee was still increasing with altitude and the peak was nowhere in sight. Another Explorer IV measurement, similar to that being prepared in the lunar package, contained a lead shielded Anton Type 302 tube. This tube registered only a modest reduction of particle counts. A new detector, the Type 213 tube, capable of indicating substantially higher radiation intensities, was substituted for the lead shielded 302 tube. A low drift electrometer-type circuit was designed to convert maximum average currents from the 213 tube into output currents having magnitudes large enough to supply signal current requirements for the associated subcarrier oscillator. Because of weight, schedule, and communications considerations, it seemed most prudent then to use an unstabilized, yet low-drift, circuit such as the one described below.

Total drift allocated to the measurement was 4 per cent of the maximum expected output excursion. Of this figure, 3 per cent was awarded to the subcarrier and 1 per cent to the amplifier. Since the subcarrier oscillator was subject to supply-voltage induced frequency shifts its supply was regulated. The remaining portion of drift could be attributed chiefly to temperature effects, and, as a result, painstaking payload temperature calibrations made it possible to reclaim much of the error that might be assigned to temperature changes.

An important aspect of the amplifier design is the dynamic range problem. Large input signals generally minimize the voltage drifts of the input differential comparator and the subcarrier oscillator. This requires that a large voltage-forming resistor be connected at the input. Current drift effects in the input stage can be reduced by inserting a similar resistor in the feedback loop. The maximum amplifier swing is limited, however, by the usable range of voltages obtainable from the payload batteries, namely 8 volts at the outset of the experiment to 6.6 volts after about 90 hours. Referring to the diagram of Fig. 3, it can be seen that if the emitters of Q1 and Q2 were returned to ground through a resistor and the emitters were expected to operate anywhere between the supply voltage and ground, the amplifier drifts due to common-mode effects would be fearsome to contemplate. A semistable constant-current source in the form of Q3 is provided for this reason. A minimum collector voltage of one volt for Q3 establishes the rest potential of the amplifier output at about 1.6 volts. The maximum output swing obtainable with a 6.6 volt supply is about 6.6 volts limited by saturation of Q1 and Q6. Of the available 5-volt dynamic range, a



Note: All NPN's are 2N336's
All PNP's are 2N329A's

Fig. 3—DC amplifier.

maximum swing of 4.2 volts was selected for measuring currents up to 40 μa. The voltage-forming resistance for these values of current and voltage is 105K.

Three factors which might contribute to amplifier voltage drift that can be assigned to the input differential comparator are

1) imperfect tracking of base-to-emitter voltages in Q1 and Q2;
2) changes in common-mode or average input currents to Q1 and Q2; and
3) changes in differential input currents to Q1 and Q2.

Under normal operating conditions ($V_{be}=0.5$ volt), the temperature coefficient of base-to-emitter voltage for silicon transistors is about −2 mv/°C at room temperature.

To insure tracking of these characteristics in Q1 and Q2, both units were selected with matching transfer characteristics (*i.e.*, V_{be} vs I_c) and, as an added precaution, similar current gains at collector currents of about 10 μa. The final amplifier drift adjustment consisted of balancing the operating points by proper selection of R3. Surprisingly, the β of the 2N336, when operated at starved collector currents of about 10 μa, was still a respectable 25–30 at room temperature.

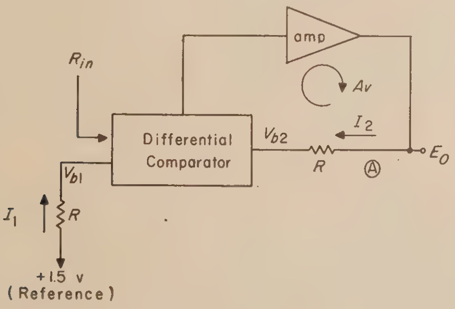


Fig. 4—DC amplifier—equivalent circuit.

To study the effects of current drifts in the differential comparator, consider the equivalent circuit in Fig. 4. In this diagram, the voltage-forming resistors connected to the base of Q1 have been replaced by their equivalent source resistance and voltage as observed from the base of Q1. If, for some reason, changes occur in the dc bias currents I_1 and I_2, the circuit voltage changes may be shown as

$$\Delta V_{b1} = -R\Delta I_1$$

and

$$\Delta V_{b2} = \Delta V_{b1} - (\Delta I_1 - \Delta I_2)R_{bb}$$

where R_{bb} is the base-to-base resistance. As a result, the change in output voltage may be written

$$\Delta E_0 = -\Delta I_1 R - (\Delta I_1 - \Delta I_2)R_{bb} + \Delta I_2 R,$$

$$\Delta E_0 = (\Delta I_2 - \Delta I_1)(R + R_{bb}).$$

The drift effect noted here is due to changes in differential base current. The value of R was 105K and a representative value of R_{bb} at the appropriate starved operating point is 150K. An output drift of 10 mv would therefore be produced by a differential current change as small as 0.04 μa. One of the mechanisms causing temperature-induced drift is change of gain in Q3. As temperature increases, the gain of Q3 increases and its collector current is correspondingly higher. Virtually all of the increase in current is absorbed by Q2. Here is a case in which differential base currents to Q1 and Q2 change and base-to-emitter voltages also become unequal. A subsidiary but nonetheless interesting corollary of unbalanced base-to-emitter voltages is that the respective emitter diodes have unequal temperature coefficients of voltage. The tracking error between two transistors having voltages of 0.4 and 0.5 volt, respectively, is about 0.33 mv/°C. To ease the multiple maladies that occurred with changing temperature, a germanium diode was inserted in the base of Q4. As temperature rose the increased I_{co} drawn by the diode was reflected back to Q1, which was now better able to absorb its share of the increased current generated by Q3. Temperature performance of a representative amplifier is shown in Table I.

TABLE I

TEMPERATURE PERFORMANCE OF DC AMPLIFIER

Temperature	Input Current (μa)	V supply =6.6 volts	V supply =7.2 volts	V supply =8.5 volts
+75°C ↓	0 20 40	1.637 3.768 5.885	1.637 3.767 5.884	1.635 3.766 5.883
+50°C ↓	0 20 40	1.624 3.758 5.867	1.623 3.757 5.865	1.622 3.755 5.862
+25°C ↓	0 20 40	1.605 3.731 5.843	1.605 3.730 5.842	1.605 3.730 5.840
0°C ↓	0 20 40	1.579 3.713 5.815	1.579 3.713 5.814	1.577 3.712 5.812
−10°C ↓	0 20 40	1.570 3.696 5.805	1.569 3.696 5.804	1.568 3.695 5.802

To insure circuit protection during early phases of payload system integration, a protective resistor was inserted in the collector of Q6. If the output is inadvertently shorted to ground, the 1-μa bias current in Q3 is amplified with full open-loop current gain thereby forcing huge currents through Q6 and the short. The 330-ohm resistor in the collector of Q6 limits current to a safe maximum and provides simple short-circuit protection.

The resistance seen looking into the base of Q1 is extremely high and can be approximated by the expression

$$R_{\text{in}} = (R + R_{bb})(1 + Av).$$

The open loop gain, Av, may be measured by breaking the loop at point A as indicated in Fig. 4 (with the input base at ac ground). The high input resistance is produced by the same bootstrap effect that reduces input capacitance to a cathode follower. This resistance is high enough so that one can no longer neglect the base-to-collector resistance of Q1. In any event, the loading on the voltage forming resistor is negligible.

The thermal operating point of Pioneers III and IV was +40°C. The drift coefficient of the amplifier described in Table I in the 40°C region was about 0.75 mv/°C.

HIGH-VOLTAGE POWER SUPPLY

The high-voltage power supply for the Geiger tubes contains a transistor-saturable-core oscillator which runs directly off the payload batteries and supplies square-wave power to a rectifier and voltage-doubler circuit. DC regulation is accomplished with a 700-volt Corona regulator. The regulated outputs of the supply are 730 volts and 650 volts for the Types 302 and 213 tubes, respectively. The high-voltage circuit, which is located inside the "crown" of the subassembly directly beneath the Geiger tubes (see Fig. 5), was foam-potted to protect against high-altitude corona discharge.

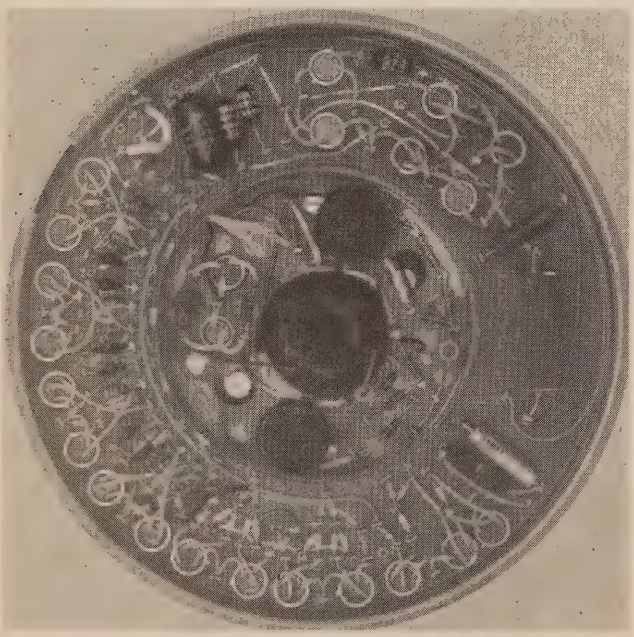


Fig. 5—Pioneer III subassembly, bottom view (power supply unfoamed).

Corona-tube idling current was selected to be a value larger than the largest expected combined Geiger-tube currents plus the minimum Corona-tube operating current. An initial idling current appreciably larger than the maximum expected load permits the regulator to handle these demands at the end of the experiment when battery voltage is low and idling current has been significantly reduced. If, for instance, maximum output were expected of both Geiger tubes near the end of the experiment (an extremely remote possibility in the vicinity of the moon), currents of about 50 μa would need to be handled by the regulator. Since the high-voltage power supply was to dissipate the major portion of power supplied to the radiation subassembly, care was required in selecting the lowest power mode of operation consistent with performance requirements. This meant that the transformer turns ratio had to be specified to provide unregulated high-voltage at minimum average power levels over the duration of the experiment. Consider the power-handling problem presented by the regulator shown in Fig. 6, which is similar to the actual regulator in the system schematic shown in Fig. 7. The power delivered by the inverter at the beginning of the experiment is $P_1 = E_1 I_1$, where E_1 is the unregulated voltage at the outset and I_1 is the regulator current expressed as $(E_1 - 700)/(R_1)$. At the end of the experiment, when the battery voltage has dropped to 6.6 volts, indicating that it has reached the limit of its useful life, the unregulated power delivered by the inverter has dropped to $P_2 = E_2 I_2$. The voltage E_1 may be written

$$E_1 = \frac{8.0}{6.6} E_2 = 1.2E_2.$$

The power delivered at the beginning of the experiment in terms of E_2 and I_2 is

$$P_1 = 1.2E_2I_2 \frac{(1.2E_2 - 700)}{(E_2 - 700)} \cdot$$

Since the battery voltage decays linearly with time, the unregulated power supplied by the inverter (see Fig. 5) falls off parabolically according to the equation

$$P_{\text{inverter}} = \frac{E(E - 700)}{R_1} \cdot$$

The power points determined by E_1 and E_2 are close enough together on this parabola that the average power delivered by the inverter over the life of the experiment may be accurately expressed by the first order approximation

$$P_{\text{average}} = \frac{(P_1 + P_2)}{2} = \frac{E_2 I_2}{2}\left[1 + \frac{1.2(1.2E_2 - 700)}{(E_2 - 700)}\right].$$

The value of E_2 yielding minimum average power is determined by differentiating the expression for P_{average} with respect to E_2 and setting this derivative equal to zero. The values of E_2 and E_1 are found to be 923 and

1110 volts, respectively. The nominal turns ratio for the transformer in this example, is 70 for the case of a lossless inverter system followed by a voltage doubler. Before designing the Pioneer high-voltage transformer, the transformer used in the historic Explorer radiation experiments[4] was tested in the inverter configuration shown in Fig. 7. A new winding specification was generated on the basis of existing estimates on payload battery voltage limits, desired unregulated output voltages, and loss measurements made with the Explorer transformer. The flight-model high-voltage power supply used a transformer having a Supermalloy core and a 90:1 step-up turns ratio. The inverter oscillated at about 2.5 kc and supplied an unregulated dc output of 1000 volts at 75 μa of idling current when the payload batteries were at 6.6 volts. Under this condition, the supply efficiency was close to 50 per cent, the majority of the extra power being dissipated in core magnetization.

The Geiger tubes used in this experiment generally drew peak ionization currents well in excess of their maximum expected average current. The filter connected to the corona tube shown in Fig. 6 limits current surges through R_2 to a small fraction of the maximum average ionization current.

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[4] G. H. Ludwig, "Cosmic-ray instrumentation in the first U. S earth satellite," *Rev. Sci. Instruments*, vol. 30, pp. 223–229; April 1959.

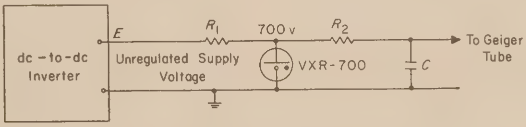
dc -to-dc Inverter
E
R_1
700 v
R_2
To Geiger Tube
Unregulated Supply Voltage
VXR-700
C

Fig. 6—High-voltage regulator.

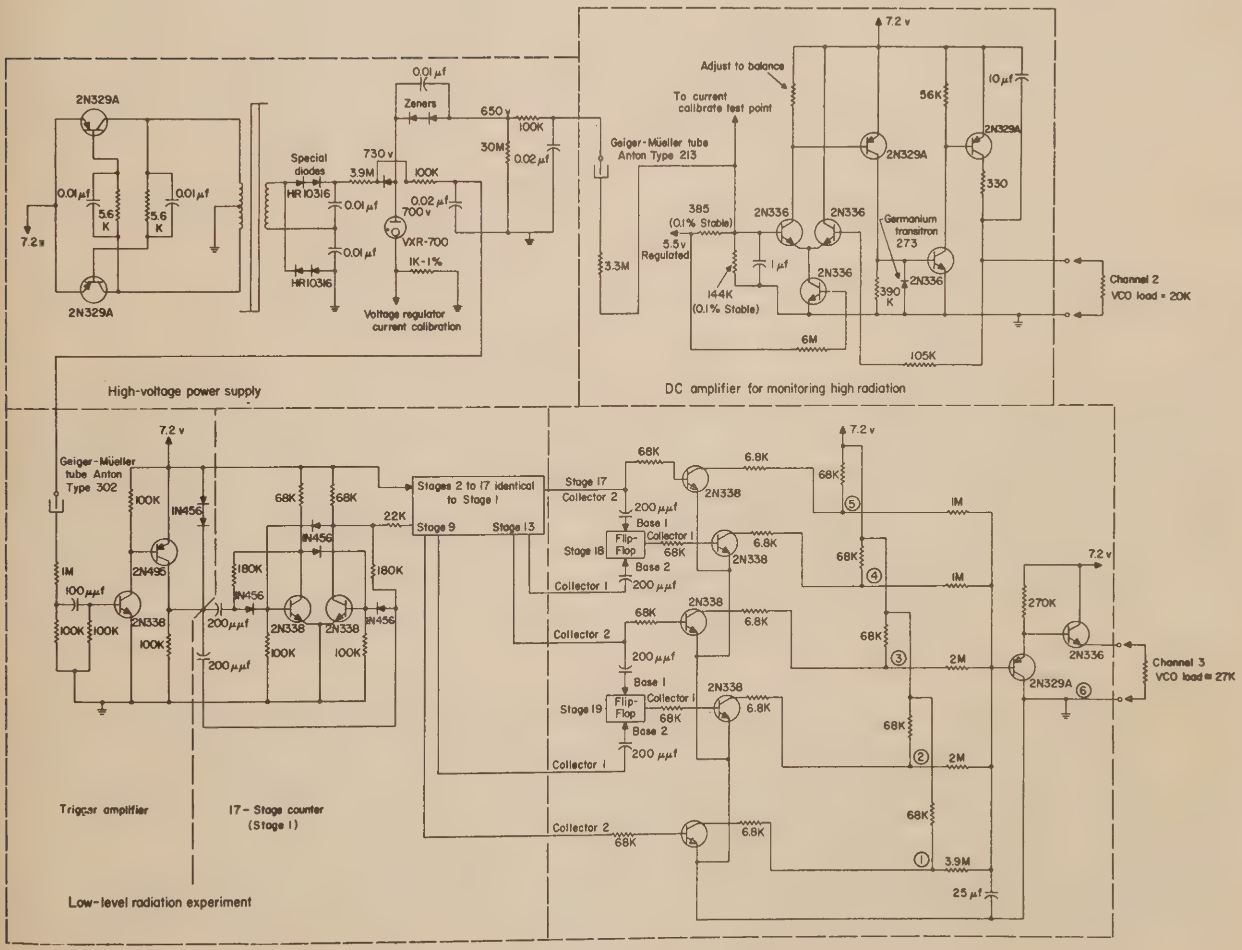
2N329A
2N329A
7.2v
0.01 μf
5.6 K
5.6 K
0.01 μf
Special diodes
HR10316
HR10316
730 v
3.9M
100K
0.01 μf
0.01 μf
0.02 μf
700 v
VXR-700
IK-1%
Voltage regulator current calibration
0.01 μf
Zeners
650 v
100K
30M
0.02 μf
High-voltage power supply
Geiger-Müeller tube Anton Type 213
3.3M
Adjust to balance
To current calibrate test point
7.2 v
56K
10 μf
2N329A
2N329A
330
385 (0.1% Stable)
5.5v Regulated
144K (0.1% Stable)
1 μf
2N336
2N336
2N336
Germanium transitron 273
2N336
390 K
6M
105K
Channel 2 VCO load = 20K
DC amplifier for monitoring high radiation
7.2 v
Geiger-Müeller tube Anton Type 302
100K
1N456
2N495
1M
100 μμf
2N338
100K
100K
100K
200 μμf
200 μμf
68K
68K
1N456
1N456
180K
180K
1N456
2N338
2N338
100K
100K
22K
Stages 2 to 17 identical to Stage 1
Stage 9
Stage 13
Trigger amplifier
17- Stage counter (Stage 1)
Low-level radiation experiment
Stage 17 Collector 2
Stage 18
Flip-Flop
Base 1
Base 2
Collector 1
Collector 1
200 μμf
200 μμf
68K
6.8K
2N338
2N338
Collector 2
Stage 19
Flip-Flop
Collector 1
Collector 2
68K
6.8K
2N338
2N338
25 μf
1M
1M
2M
2M
3.9M
68K
⑤ ④ ③ ② ①
7.2 v
270K
2N336
2N329A ⑥
Channel 3 VCO load = 27K

Fig. 7—Schematic: radiation experiment, Pioneers III and IV.

DIGITAL EXPERIMENT

Pulse-Forming Circuits

The circuitry connected to the shell of the Type 302 tube consists of an ionization-current-limiting resistor and an RC network coupled to the trigger amplifier (see Fig. 7). The diodes at the output of the trigger amplifier establish standard pulse amplitudes of about 1.2 volts. The input capacitor and emitter diode of the first transistor in the trigger amplifier produce a dc restoration effect similar to the one required for television video signals. The positive pulse signal has its peak restored to +0.6 volt by the transistor base-to-emitter diode. Since base current flows only during the first 10 or 15 μsec after the ionizing event and is induced only by the ionization signal peak, there is no danger of trigger amplifier saturation for the closest spaced pulses.

Counting Range

The maximum average rate at which the Type 302 tube will count, as determined by tube dead time, is about 16,000 to 18,000 counts per second. Dead time is that period of insensitivity in the tube during which no other ionizing events can be detected. At the end of this time, the field encircling the center conductor of the tube has reached its threshold value. The recovery time is the additional increment needed to restore the second pulse to its full height.[5] Both effects are illustrated in Fig. 8. When particle counting rates are far in excess of the maximum counting ability of the tube, an increasing percentage of the particles will either not be counted or will produce ionizations occurring at intervals slightly larger than the dead time. Peak-to-peak amplitude of the closely spaced pulses will be sharply attenuated resulting in a smaller percentage of the pulses being large enough to trigger the input stage of the scaler. The reduced pulse amplitude has the effect of producing a double-valued calibration curve. In the region where the apparent count rate reaches a peak and then drops off, the analog channel produces an output that still varies monotonically with radiation intensity. Therefore, the pulse integrator circuit used as a high-intensity monitor also resolves ambiguities in the digital channel caused by the double-valued nature of its response. Maximum average count rates obtainable in Pioneers III and IV were about 12,000 counts per second.

Scaler Chain

The basic flip-flop (see Fig. 9) used in the scaler chain is a saturating transistor device capable of operation up to 100,000 counts per second with fixed amplitude triggers. The flip-flop performs with "semistarved" collector currents of 100 μa per collector, dissipating 1.4 milliwatts per stage. This circuit is by no means fast, in terms of modern high-speed computer devices, but it is more than adequate for the Geiger tube counting rates encountered in this experiment. In addition, it is an unquestionably reliable tool in terms of most missile or space vehicle environments. A noteworthy aspect of the flip-flop performance is its ability to operate on, and also deliver, trigger pulses of relatively constant amplitude irrespective of supply voltage. To a certain extent this is true of most direct-coupled transistor flip-flops. The cross-coupling diodes abetted by the conventional silicon transistor base-operating potentials standardize the output swing at 1.1 to 1.2 volts. The diodes are also instrumental in promoting fast regeneration for flip-flops operating at low currents with the associated degraded transistor characteristics. "Turn-off" of a saturated device, for instance, is aided by the storage properties of the diode which replace corresponding properties of the conventional cross-coupling resistor and its charged parallel speed-up capacitor.

The steering diodes provide 1.1 volts of positive trigger rejection to the ON transistor which prevents double triggering. The operating point of the OFF transistor base is such as to provide at least 2 μa of I_{co} protection before multiplication takes place.

The entire chain of 17 flip-flops plus the two auxiliary stages were demonstrated to operate reliably between the relatively wide supply-voltage limits of 2 and 20 volts at 25°C. Similar performance was obtained between 5 and 10 volts between ambient temperature extremes of −15°C and +75°C.

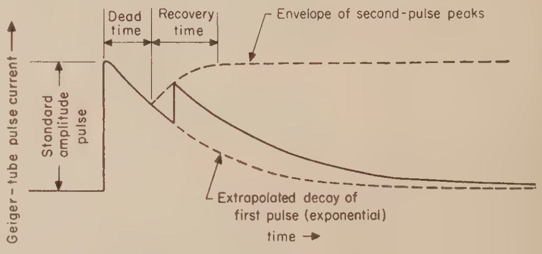

Fig. 8—Reduction in amplitude caused by recovery-time effects.

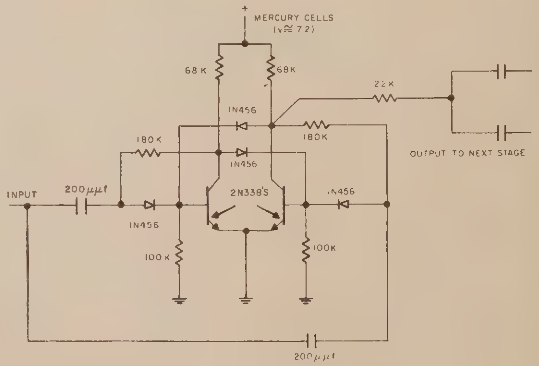

Fig. 9—Basic scaler flip-flop circuit.

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[5] S. A. Korff, "Electron and Nuclear Counters," D. Van Nostrand Company, Inc., New York, N. Y., ch. 4, pp. 130–131; 1955.

Coding

To improve the readability of the scaler output caused by a pulse input having a widely varying counting rate, three outputs were selected at four-stage intervals. These signals are mixed in the ratio of 1:2:4 for the first, second, and last tap, respectively. The result is the consolidation into one subcarrier of information that might ordinarily require three subcarriers. Reading speeds of slow counting rates are thereby improved by as much as 256:1 over that obtained from a single tap at the end of an identical number of counter stages. As a corollary, this coding process also minimizes the number of variable speed playbacks of the telemetry magnetic tapes needed for clear, readable information. This unfiltered composite waveform is shown in Fig. 10. The uncompensated mixed waveform produces a large voltage step once every 2^{17} pulses or once every major scaler cycle. To preclude the occurrence of correspondingly large step changes in frequency at the output of the subcarrier oscillator, an auxiliary flip-flop (stage 18 in Fig. 7) provides step reduction at the critical point. Similar compensation is performed on the subcycle by stage 19. The step reduction mechanism permits minimization of the output shaping-filter time constant for given values of subcarrier band swing. Actual radiation telemetering data received on the re-entry leg of the Pioneer III trajectory is illustrated in Fig. 11.

Scaler Length

The scaler chain was made long enough to prevent the fastest expected output signal appearing at the last stage from being severely attenuated by the shaping filter in the mixing circuit. By shaping the output square-waves into exponentially rising and falling edges, steady-state signal phase error occurring in the microlock receiver subcarrier phase-locked loop could be fixed at a tolerable maximum. In broad terms, the scaler length is indirectly determined by such interrelated items as sideband power, receiver loop-bandwidth, and signal-to-noise ratios at threshold distances.

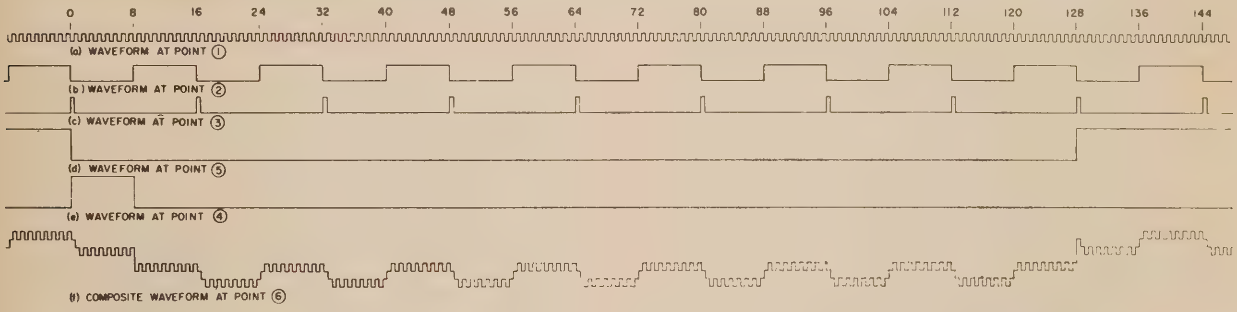

Fig. 10—Individual and composite digital waveforms. Amplitude of waveforms in (a)-(e) are illustrated according to relative weighting in the mixer circuit. Waveform locations are referenced to points in the schematic and block diagram.

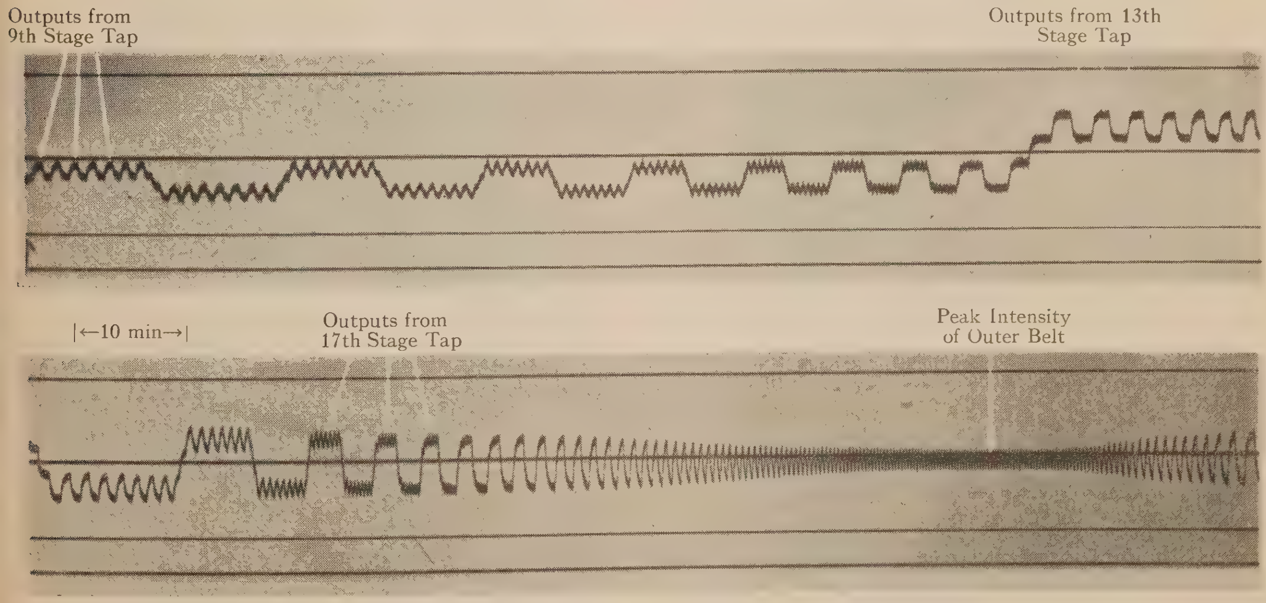

Fig. 11—Pioneer III re-entry radiation data monitored at Mayaguez, Puerto Rico (subcarrier frequency vs time).

COMPONENT CONTROL

The corona regulator used in the high-voltage power supply was the Victoreen VXR-700; the same type flown in the early Explorers. The volt-ampere characteristics of all incoming tubes were measured at the nominal operating temperature and also at the ambient extremes. All high-voltage rectifier diodes were inspected for reverse leakage currents at their rated peak inverse voltages over the same range of operating temperatures as used in testing the regulator tubes. Similarly, the low voltage Zener Diodes, used to adjust the high voltages applied to the Geiger tubes, were thoroughly tested.

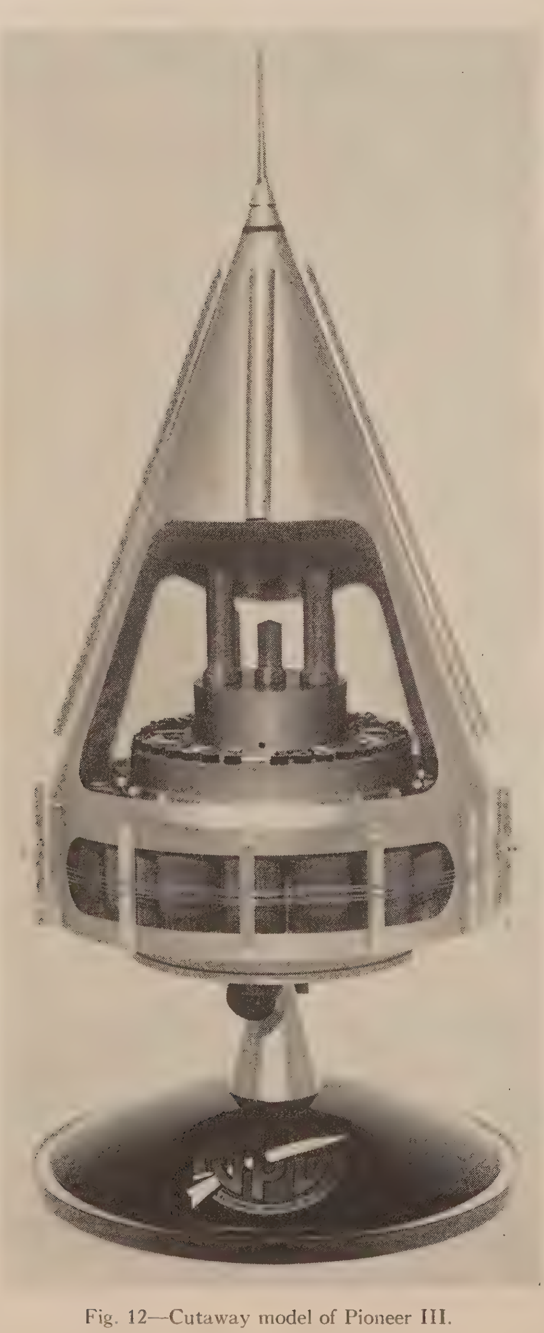

Fig. 12—Cutaway model of Pioneer III.

Part of the cooperative effort between SUI and JPL involved precalibration of all flight-approved Geiger tubes at SUI. Four final tests were performed on the Geiger tubes after they were installed in the subassembly. Before the internal high-voltage connections were made to the tubes and before the supply and Geiger tubes were foamed into place, threshold or starting voltage measurements were made on both the Type 302 and 213 tubes. A pleateau measurement was then run on the 302 tube. After the high-voltage connections were completed, radiation-induced ionization pulses were inspected for height and dead time across the current limiting resistors. Typical values of dead time for the 302 tubes were 60 μsec. The maximum linear counting rate is less than 1/(dead time) because of statistical particle pile-up effects.

All transistors used in the scaler flip-flop circuits were inspected for switching current gains. The switching gain in this application was defined as the dc value of β at the 100-μa knee of the common-emitter collector characteristic. Transient switching characteristics of these transistors were also logged. All 2N336 transistors

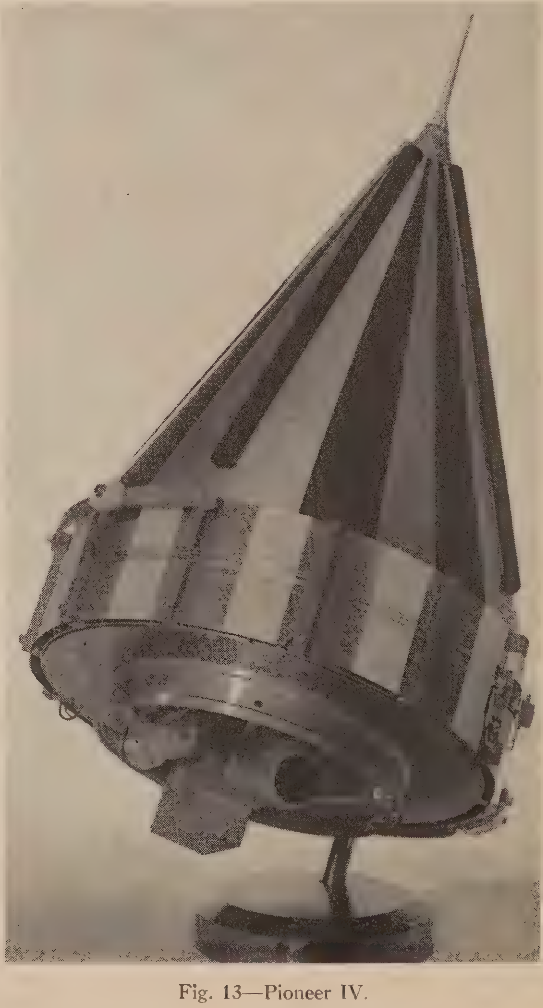

Fig. 13—Pioneer IV.

used in the dc amplifier were checked at 2 collector-current points for dc β and base-to-emitter voltage for subsequent matching.

ENVIRONMENT

A total of seven subassemblies was constructed during the course of the project. The first two were slated for type-approval tests and met the most severe set of environmental conditions that flight units might encounter. The next five were designated as flight hardware. The flight-acceptance environment was not quite so severe as the type approval in order that each flight unit might have a better flight-life expectancy.

The following flight-acceptance tests were performed on the subassembly by itself and again on the payload system, which is shown in two forms in Figs. 12 and 13.

1) Temperature:	−10°C to +75°C (subassembly) +25°C to +45°C (payload)
2) Acceleration:	a) Flight Plane: 65 *g* for 1 minute b) Spin: 750 rpm for 5 minutes
3) Altitude:	150 microns of Hg
4) Vibration:	10 *g* rms white noise between 20–1500 cps with 25 *g* bursts (0.2 second duration)
5) Shock:	100 *g*
6) Despin:	750 rpm to 6 rpm

CONCLUSION

This paper has described an electronic device characteristic of first generation scientific space instruments. Perhaps the device itself is only of academic interest in the instrument field although the scientific results, such as the radiation data transmitted to the JPL downrange station in Puerto Rico, by the instrument, are decidedly of more than just casual interest.

ACKNOWLEDGMENT

Much credit is due D. W. Slaughter for his contributions to the digital phase of this experiment. Encoding suggestions made by W. K. Victor at the outset of the project were used in the final design. The group technicians who constructed the subassemblies and earnestly performed seemingly endless testing and evaluation deserve a large measure of gratitude for their important contributions.

The author wishes to thank Dr. Van Allen and his staff at SUI for their cooperation in the preparation of the experiments. The careful integration and handling of the Pioneer payloads by the JPL Payload Systems Group, under the direction of D. Schneiderman, contributed notably to the success of the missions.

Stability of Rotating Space Vehicles*

H. L. NEWKIRK†, W. R. HASELTINE†, AND A. V. PRATT†

Summary—**The problem of stabilizing space vehicles is considered, and it is shown that at least for some important applications the intrinsic stabilization obtained by rotation of the entire vehicle is advantageous. Investigations which have been made of natural methods for damping nutational vibrations of such rotating vehicles are discussed in the following manner.**

A laboratory simulator is described which has been found very useful in testing the various devices suggested for nutation damping. A number of references to recent analytical studies of nutation dampers are given. One approach, a rigorous attack on a simplified arrangement, is described in some detail. Also, formulas based on an intuitive approach are derived for the design of both the pendulum and the mercury dampers. Finally, an interesting and, it is believed, entirely new basic design criterion for stable operation of coupled rotating bodies, such as a space vehicle with pendulum nutation dampers, is demonstrated.

INTRODUCTION

A NONROTATING rigid body in space possesses little or no inherent stability, since even a small torque exerted for a short time will result in some angular velocity, or tumbling, which continues until countered by an equal and opposite torque. However, a similar rigid body which is rotating has an angular momentum vector with a direction fixed in space. This direction will change as the result of a torque on the body normal to the momentum axis, but it continues to change only as long as the torque is applied and then it will stop. Spinning a space vehicle, therefore, provides a kind of intrinsic stability or resistance to disturbing torques and, although it may be quite possible to stabilize a nonrotat-vehicle by means of an independent inertial reference controlling a system of jets, stabilization based on a natural property, such as spin of the entire vehicle, should be more economical as well as more reliable.

For some space vehicles there may be functional objections to spin but for many applications spin will actually fulfill specific requirements other than stability. As an example: the large space stations are invariably envisioned as spinning slowly to provide a force field or artificial gravity in the living quarters which are located

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* Original manuscript received by the IRE, November 23, 1959.

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at a distance from the center of rotation. On a much smaller scale, present-day vehicles intended to view the moon surface or the earth's cloud cover are designed to rotate about an axis normal to that of the telescope.[1] This provides automatic scanning of the area to be viewed. There are, undoubtedly, many other applications for rotation in space vehicles and, because of the intrinsic nature of spin stabilization, thorough study of the dynamics of the spinning space vehicle is well warranted.

It was noted that the momentum axis of a spinning body would change direction under an applied torque normal to this axis, and when the torque is released the motion would stop. However, the spin axis may continue to move in a nutational vibration. Here, as in mechanics texts, the motion of the axis of rotation under such an external torque is termed "precession." During precession the total angular momentum vector of the body actually changes in direction. By contrast "nutation" describes the rotary oscillations of the spin axis of the body about the total angular momentum vector. Nutation is a vibratory type of motion like that of a mass attached to the end of a thin, spring-steel member and taking a rotary motion about the equilibrium position; similarly, nutation occurs as the result of the initial conditions being different from a stable state. Nutation can occur simultaneously with, and superimposed upon, precession, which can give rise to the familiar epicyclic or bobbing motion of a common top.

In order to change the attitude of a rotating space vehicle, probably the simplest method is to precess it by means of a pair of jets fixed in the vehicle. The jet torque must therefore operate during a portion of each revolution (for example 90°) for successive revolutions of the vehicle until the desired precessional angle has been attained. Note that the jets can be made to operate in any sector during a revolution of the vehicle so that the axis can be precessed toward any desired direction by a single jet fixed system. However, the torque causing the desired precession is not constant or even slowly varying but occurs in a series of discontinuous pulses in synchronism with the spin, and nutational vibrations can be expected from this as well as from other disturbances. For most applications the nutation is objectionable if not intolerable, and should be damped as quickly as possible to a negligible value.

As with the basic attitude control, damping could probably be accomplished with an independent inertial reference and jets. However, again there appear to be natural methods to obtain nutation damping, using passive instead of active devices.

A similar need for damping nutational vibrations has arisen in the design of various guidance components which depend on gyroscopic action. A very effective solution has been the mercury damper. In one design this consists of two circular channels in a disk mounted concentric with the axis of the gyroscope wheel. The channels are only partially filled with mercury so that it can move freely within them. As discussed in a later section, apparently the diameter of the channels in relation to the other system parameters influences the effectiveness of the damping, and the design has provided excellent damping characteristics.

However, when the mercury damper was proposed for space vehicles an objection was raised. It appears that the same (passive) device which produces damping in a disk-shaped object rotating about the axis of greatest moment of inertia will cause an undamping of nutations in a cigar-shaped vehicle rotating about its longitudinal axis. It is usually quite feasible to construct a space vehicle *payload* shaped basically like a short, flat cylinder. However, rocket boosters are conventionally long compared to their diameter and, since the firing of the last booster stage is often preceded by a long coast period after which the direction of its thrust is important, there is much concern over stability. It would be highly desirable, therefore, to have a nutation damper which could be incapacitated, or which is known to be ineffective during the boost stages, but which is extremely effective in the final space vehicle.

SPACE VEHICLE DYNAMICAL SIMULATION

Theoretical attacks on this nutation damper problem have proven very frustrating, and a simulator was designed in an attempt to investigate in the laboratory the nature of the motions with various damping devices and missile dynamical configurations. This device is shown in Fig. 1. By changing the separation of the two large rings, which are made of heavy copper, on the light aluminum center cylinder, the transverse moment of inertia, B, can be changed with respect to the polar moment of inertia, A. In this way the ratio A/B can be varied from about 0.7 to 1.55. The symmetry axis of the unit is adequately defined by the steel shaft at the top, and this also serves for attaching various experimental devices for nutation damping. The entire unit is mounted near the center of the aluminum cylinder on very low-friction gimbal bearings or, better, on a hardened steel or jewel cone and cup bearing. The skirt of the aluminum cylinder limits the sideways tipping to about 20°, but this has not been seriously restrictive. By moving both large rings up or down; the center of gravity of the unit can be placed at the center of support or at a distance from it along the main axis, as desired. In addition, there is provision for a semipermanent transverse adjustment of the center of support. This "top" is given sufficient spin by merely twirling it with the fingers, *e.g.*, 5 to 10 rps.

By means of the top and a stroboscope, many features of standard gyroscopic theory are easily checked. Various precession rates, including zero, can be obtained. Nutations are sustained, undamped (for the rigid body), over long periods so that it is easy to see, for example, that nutation frequency is higher than spin for $A/B>1$ and lower for $A/B<1$. It was quickly demonstrated that an effective nutation damper was, in fact, an undamper when $A/B<1$. It is noted, however, that if the friction in the spin bearing becomes too high it has a damping effect on nutations, and test results under this condition will be deceiving.

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[1] R. G. McCarty, "Designing small space loads," *Astronautics*, vol. 4, p. 24; May, 1959.

A sample of the damping devices tested with this top is shown in Fig. 2. It has been found quite easy to explore or test out ideas for new types of damping devices. Qualitative tests of an idea are usually sufficient to answer most immediate questions. By means of a stop watch and rough observations of nutation amplitude semiquantitative results can be obtained. For quantitative determinations motion pictures can be taken. The frame rate need not be high, 64 to 90 frames per second is sufficient, but a very narrow shutter angle such as 10° should be employed to minimize blurring. Although it may be somewhat tedious, measurements can be made of 1) spin angle, 2) attitude of the axis of the top, 3) position of the damping device or its components. These data can be plotted or analyzed to show quantitatively the relations between spin, nutation, precession, and functioning of damper parts.

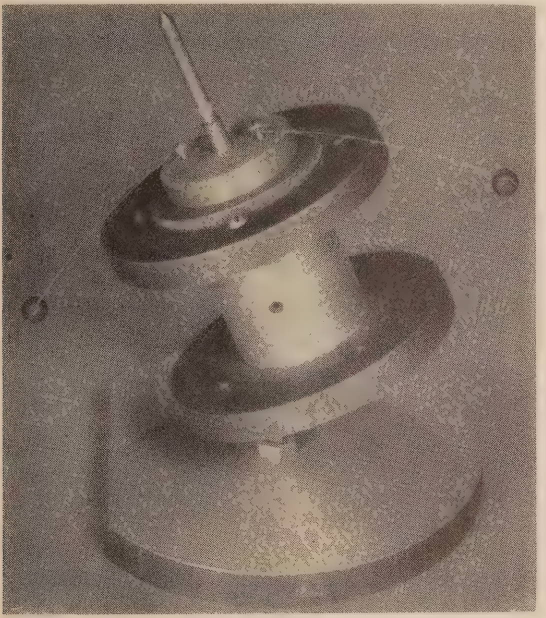

Fig. 1—Space vehicle dynamical simulator.

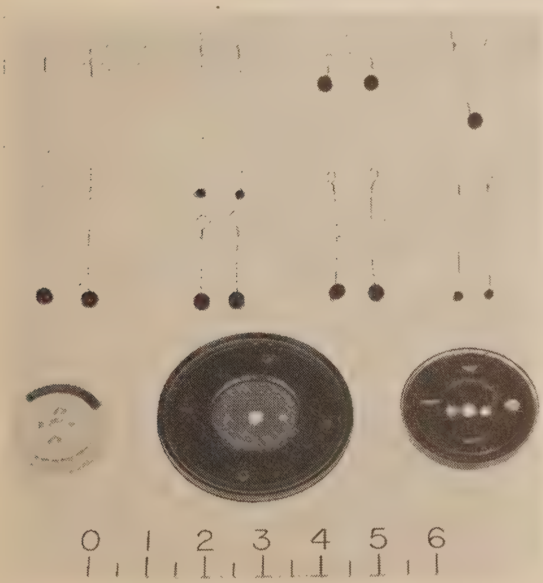

Fig. 2—Experimental nutation damper.

ANALYSIS

Although photographs have been taken, experiments to date have only been semiquantitative. They have, however, indicated that there is more than one mechanism, some probably more effective at large amplitudes, and others at small. Studies of various aspects of the problem have been made[2–9] which in general tend to support this observation. Theories which depend entirely on frictional dissipation to absorb nutational energy do not seem to be nearly fast enough.

A more recent analysis[9] has probably followed the most rigorous approach, and in it the effect of some of the approximations finally made were tested by analog computor methods. The specific problem treated is that of a single small mass constrained to move in a plane normal to the axis of the top and at a fixed radius from this axis. This can be, for example, a small mass on the end of a light, rigid arm hung on the axis of the top, or a small drop of mercury in a channel concentric with the axis.

The moving coordinates chosen are aligned with the symmetry axis of the rotating rigid body, *i.e.*, the top, with the origin at the center of gravity of the top. However, the coordinate system rotates with the small damper mass instead of with the top (Fig. 3). Euler rotations from the nonrotating coordinates, x_0, y_0, z_0, are shown in Fig. 4 as follows: 1) rotation, ϕ, about the fixed vertical axis, z_0; 2) rotation, θ, about the new x, which will be the line of nodes; 3) rotation, ψ, about the

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[2] F. H. Davis, "Gyro Nutation Damping," U. S. Naval Ord. Test Sta., China Lake, Calif., NOTS Internal Memo.; March 10, 1959.

[3] F. H. Davis, "Oscillations of a Disc-Shaped Pendulum Mounted on a Spinning Body," U. S. Naval Ord. Test Sta., China Lake, Calif., NOTS Internal Memo.; July, 1959.

[4] W. F. Cartwright, U. S. Naval Ord. Test Station, China Lake, Calif., unpublished NOTS Internal Memos. on the Nutation Damper; July 12, 1958, July 22, 1958, and others.

[5] E. E. Rogers, "A Mathematical Model for Predicting the Damping Time of a Mercury Damper," U. S. Naval Ord. Test Sta., China Lake, Calif., NOTS Internal Memo. No. IDP 565; March 2, 1959.

[6] D. J. Stewart, "Nutation Damper," U. S. Naval Ord. Test Sta., China Lake, Calif., U. S. Patent No. 2,734,384; February 14, 1956.

[7] J. M. Boyle, "Invention Disclosure for Nutation Damper," U. S. Naval Ord. Test Sta., China Lake, Calif., Navy Case No. 25,818; September 10, 1957. (Currently inactivated.)

[8] G. F. Carrier, "The Theory of the Annular Damper," Space Technology Labs., Los Angeles, Calif., Rept. No. GM-TM-0165-00265; July 21, 1958.

[9] A. V. Pratt, "Theory of the Unsymmetrical Nutation Damper," U. S. Naval Ord. Test Sta., China Lake, Calif., NOTS Internal Memo. No. TN-4065-63. (In press.)

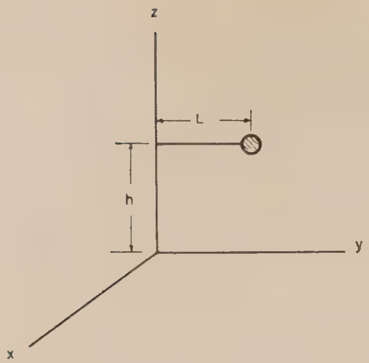

Fig. 3—Damper mass, m, fixed in rotating coordinate system.

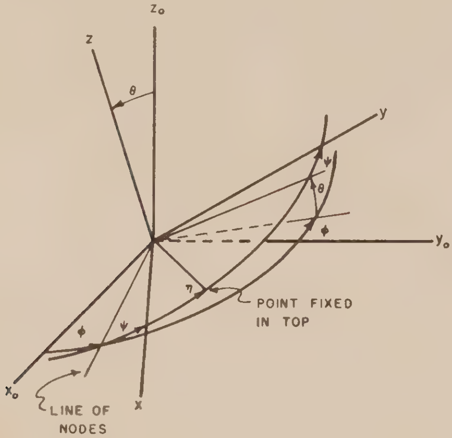

Fig. 4—Fixed and moving coordinates showing Euler angles and η.

final z, which is also the axis of symmetry of the top. Finally, to reach a fixed point in the top from the x, z plane, an additional rotation, η, about z is required.

It is assumed that no external forces or moments are acting, and the frictional coupling between the small mass and the top produces a force *not* resulting from a potential function. Therefore the Lagrangian of the system is simply the sum of the kinetic energies of the top and the small mass. This is

$$T = \tfrac{1}{2}[A\Omega^2 + B(\omega_x^2 + \omega_y^2) + MV_M^2 + mV_m^2],$$

where ω_x, ω_y, (and ω_z, used later) are the components of the total angular velocity of the moving coordinate system along the moving axes indicated by the subscripts; Ω is the component of angular velocity of the top along z, *i.e.*, spin (note that $\Omega = \omega_z + \dot{\eta}$); V_M, V_m are velocities of the top and of the damper, respectively; M, m are masses of the top and of the damper respectively; and A, B are polar and transverse moments of inertia, respectively, of the top. This reduces to

$$T = \tfrac{1}{2}[A\Omega^2 + B(\omega_x^2 + \omega_y^2) + \bar{m}(\Omega \times r_m)^2],$$

where $\bar{m} = m\ [M/(M+m)]$ is a "reduced" damper mass, and r_m is the distance from the center of gravity (cg) of the top to the damper mass.

The generalized coordinates, q_i, of the Lagrange equations are the three Euler angles of the moving coordinate system, in which the damper mass is fixed, and the angle η between x and a reference point in the x, y, plane in the top. In terms of these the four angular velocities in the expression for T are

$$\omega_x = \dot{\phi} \sin\theta \sin\psi + \dot{\theta}\cos\psi$$
$$\omega_y = \dot{\phi} \sin\theta \cos\psi - \dot{\theta}\sin\psi$$
$$\omega_z = \dot{\phi}\cos\theta + \dot{\psi}$$
$$\Omega = \omega_z + \dot{\eta}$$

in which dots show differention with respect to time. These are substituted into T and the result differentiated as indicated in the modified Lagrange equations:

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{q}_i}\right) = M_{q_i}.$$

The M_{q_i} are all zero except that

$$M_\eta = -k\dot{\eta},$$

in which simple viscous friction alone (with coefficient, k) is assumed. The four equations which result can be reduced to the following in which it has been possible to eliminate the trigonometrical functions.

$$\dot{\Omega} = -\frac{k}{A}(\Omega - \omega_z).$$

$$\dot{\omega}_z = \frac{\bar{B}k}{\bar{B}C - D^2}(\Omega - \omega_z) + \frac{AD}{\bar{B}C - D^2}\Omega\omega_x + \omega_x\omega_y.$$

$$\dot{\omega}_y = -\omega_z\omega_x + \frac{AC}{\bar{B}C - D^2}\Omega\omega_x + \frac{Dk}{\bar{B}C - D^2}(\Omega - \omega_z).$$

$$\dot{\omega}_x = \frac{\bar{B} - C}{\bar{B} + C}\omega_z\omega_y - \frac{A}{\bar{B} + C}\Omega\omega_y - \frac{D}{\bar{B} + C}(\omega_z^2 - \omega_y^2).$$

Here the new symbols are as follows:

$$\bar{B} = B + \bar{m}L^2$$
$$C = \bar{m}h^2$$
$$D = \bar{m}hL.$$

h, L are the y and z coordinates, respectively, of the damper mass.

These equations are exact for this particular problem, without small angle or other limiting approximations. The case should be good for a vehicle in space without (gimbal) bearing friction if the frictional coupling to the damper mass is indeed entirely through viscous friction.

If the nutation angle, θ, is kept small and if the damper mass is much less than the mass of the top, the following simplified equations are obtained:

$$\dot{\Omega} = 0.$$

$$\dot{\omega}_z = -\frac{k}{C}(\omega_z - \Omega) + \frac{AD}{BC}\Omega\omega_x.$$

$$\dot{\omega}_x = \omega_z\omega_y - \frac{A}{B}\,\Omega\omega_y - \frac{D}{B}\,\omega_z{}^2.$$

$$\dot{\omega}_y = -\,\omega_z\omega_x + \frac{A}{B}\,\Omega\omega_x.$$

The difference between these two sets of equations in determining angular velocities was shown to be small under the limiting conditions by analog computor simulations.

In studying the equations for nutation damping one can examine the angular velocities to learn, for example, how fast ω_x and ω_y become small under various initial conditions and relationships of the parameters. However, these angular velocities are difficult to measure accurately in an experiment, and an expression for the nutation angle itself is greatly to be desired. After much algebra but without further limiting assumptions the following differential equations were obtained.

$$\ddot{R} = -\frac{k}{c}(\dot{R} - \Omega) + \frac{AD}{2BC}\,\Omega(\dot{Z}e^{-iR} + \dot{\bar{Z}}e^{iR}),$$

$$\ddot{Z} - i\frac{A}{B}\,\Omega\dot{Z} = -\frac{D}{B}\,\dot{R}^2e^{iR},$$

in which $R \equiv \phi + \psi$ is approximately the rotation angle of the coordinate system (and the damper mass). Note that

$$\dot{R} \doteq \omega_z$$

$$Z \equiv \sin\theta(\cos\psi + i\sin\psi)$$

so that

$$|Z| = \sin\theta \doteq \dot{\theta}.$$

It will be remembered that, in the approximation, the spin of the top, Ω, is considered to be constant.

It is evident that these equations are extremely difficult to solve in the general sense. However, three different simplified probable cases were examined. The first is the observed stable situation in which the damper does not rotate relative to the top. The expected limit cycle results in which $|Z| \doteq \theta_0 = \text{constant}$.

For the second condition the damper oscillates at a small amplitude with respect to a fixed point in the spinning top. This is called the "slow damping" case. The solution consists of a constant term and successive terms decreasing the nutation angle with time. This can be put into exponential form and the value for the time constant (in which the amplitude is reduced to $1/e$ of an initial value) is given by

$$t_C = \frac{2(A-B)BC^2\left[\left(\frac{k}{C}\right)^2 + \left(\frac{A-B}{C}\right)^2\Omega^2\right]}{AD^2\Omega k}.$$

Analog computer solutions indicate that the time given by this formula is a little too long.

A third solution attempted, called the "fast damping" case postulates that the damper mass rotates at the nutation frequency. No reasonable exponential form for the solution of this case could be written. However, the nutation amplitude during any single nutation cycle is indicated approximately by

$$\theta^2 = \theta_0{}^2 - \left(\frac{2k(A-B)}{AB} - \frac{2\pi D^2A\Omega}{B^3}\right)t.$$

This relation appears to hold fairly well until θ approaches a minimum value below which the solution no longer exists.

Investigation is being continued with this simplified model which should further the accurate analysis of more practical designs. The attack is threefold, employing the experimental model and the analog computer to substantiate and to stimulate mathematical analysis. It appears to date that in the most powerful mechanisms the damper plays the part of a catalyst, an engine or a coupling which causes or makes possible the transfer of energy or momentum from the nutational vibration to the axial spin.

INTUITIVE DESIGN CRITERIA

The simple device discussed analytically above, which may consist of a small weight hung on the shaft of a top by a length of fine, stiff wire, provides good nutation damping (or undamping for $A/B < 1$). But a small unbalance is created causing the stable rotation to be about some axis other than the shaft axis and at random orientation from it. This makes it impossible to arrange internal components of a space vehicle so that any one part will always be on the final stable axis of rotation. However, the orientation can be predetermined if a fixed unbalance is introduced in the top or, similarly, if the pivot point for the pendulum-like damper is a pin offset to one side of the top's center shaft. This suggests the Frahm vibration absorber as discussed by DenHartog.[10] To bring the stable axis of rotation back to the shaft, *i.e.*, the axis of symmetry, a counterbalance weight can be introduced opposite to the pendulum as proposed by Davis.[11] The obvious extension of this is to employ two diametrically opposed pivot pins and pendulums designed to counterbalance each other when in the stable state of rotation of the top. As described later, the stable state of rotation is controlled by more design parameters than just the weight of these opposed pendulums. However, it is sufficient now to note that, for certain conditions this double pendulum damper approaches the effectiveness of the mercury damper in tests made with this top. Even though the complete and rigorous theory is not available for these dampers, it may be of interest to show here a naive or intuitive approach to the design of both the pendulum and the mercury dampers which appears to work. In both cases the treatment is only slightly modified from that indicated by Davis.

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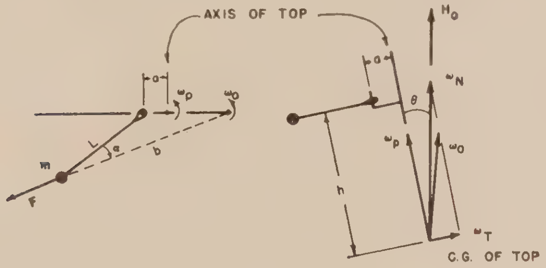
[10] J. P. DenHartog, "Mechanical Vibrations," McGraw-Hill Book Co., Inc., New York, N. Y., 3rd ed.; 1953.

[11] This and the offset pivot were suggested by F. H. Davis of the U. S. Naval Ord. Test Sta., China Lake, Calif.

Pendulum Nutation Damper

First considered is the pendulum type of damper. The pendulum is in a centrifugal force field with lines radiating from the instantaneous center of rotation, ω_0. In Fig. 5(a) this is shown as the force F, on mass, m, directed along a radius, b, from ω_0. The axis of the top is labelled with its spin, ω_p, and the peg is shown at distance, a, from ω_p. We assume for simplicity that these points remain in a line, which they actually do *only* if the nutation angle, θ, is constant and there is no damper attached. This line is in the plane containing the angular momentum and spin vectors as shown in Fig. 5(b).



(a') (b)

Fig. 5—Pendulum damper parameters.

With this simplified picture, it is easy to find the following formula for the frequency of the pendulum which should be considered only for very small θ:

$$\text{frequency} \equiv \frac{\omega_\beta}{2\pi} = \frac{\omega_0}{2\pi}\sqrt{\frac{a}{L} + \frac{hA}{LB}\tan\theta}.$$

Here we have employed the classical relation between the nutation rate, ω_N, its angle, θ, and the polar and transverse moments of inertia, A and B, respectively, *i.e.*,

$$\frac{\omega_N}{\omega_p} = \frac{A}{B\cos\theta}$$

and the relation illustrated, *i.e.*,

$$\omega_T = \omega_N \sin\theta.$$

We reason now that if this is to be a vibration absorber, the pendulum frequency should be tuned for the disturbing frequency, namely the nutation frequency, ω_N. However, since the pendulum is spinning with the top it will not "see" ω_N but the difference between this and the spin frequency. Therefore, we set

$$\omega_\beta = \omega_N - \omega_p,$$

and solve for the relation between the parameters to find that the length of the pendulum should be

$$L \doteq \frac{a + Ih\theta}{(I-1)^2} \rightarrow \frac{a}{(I-1)^2}$$

where $I = A/B$ is the ratio of the polar to the transverse moments of inertia and where small angle approximations have been made for functions of θ; also, we have let $|\omega_0| = |\omega_p|$. The formal or mechanical substitution of terms shows that the tuning depends on the amplitude of nutation, θ. However, since the relation is suspect for significant values of θ, damper design should probably be based on the first term only, as indicated by the arrow.

If I is not far above unity, the required L may be excessively long. A compound pendulum having radius of gyration, ρ, about its center of gravity can then be designed according to the following:

$$L = \frac{a + Ih\theta}{(I-1)^2} \frac{1}{(1 + \rho^2/L^2)}.$$

This pendulum can be a disk or a ring attached so that ρ/L is large.

As has been noted, an arrangement in which two of these pendulums are hung on diametrically opposed pegs forms an extremely effective balanced damper. The two pendulums can be tuned to different frequencies to broaden the most effective damping range; but the centrifugal force created by each, in the stable state, should be the same for good balance.

Mercury Nutation Damper

For the mercury damper the approach is similar. As noted earlier, this damper consists of one or more circular channels affixed concentrically about the axis of the top. For a space vehicle they would be mounted some distance from the center of gravity. Each channel is filled with a certain amount of mercury as discussed in the following. There must be sufficient mercury to form a complete ring in the channel when the top is spinning smoothly about its axis.

Let the radial depth of mercury in this ring be d and call the centrifugal acceleration g^*. Then the velocity of a wave in the mercury is

$$V = \sqrt{g^* d}.$$

This holds when the depth is small compared to the wavelength; the velocity will be lower if the depth becomes proportionately greater. If this velocity is divided by the circumference of the mercury surface we obtain the frequency with which a wave travels around the channel circle. The principle is to match this frequency to the disturbance frequency "seen" by the mercury; that is, $(\omega_N - \omega_p)$ as with the pendulum. Here $g^* = L\omega_0^2$, so that

$$\omega_M = \frac{V}{L} = \frac{\sqrt{L\omega_0^2 d}}{L} = (\omega_N - \omega_p).$$

Then $d=L(I-1)^2$ is radial depth of liquid. The symbols are as before except that L represents the radius from the top axis to the inner mercury surface when the top is "sleeping." The same small angle approximations have been made as for the pendulum. Two or more channels, if used, can be tuned to somewhat different frequencies to broaden the effective range.

An alternative damping mechanism for the mercury is also suggested by Davis.[2] Since the nutation rate is greater than the spin, the mercury is driven to rotate in its channel faster than the top. By the frictional coupling the mercury tends to increase the spin of the top. This mechanism would transfer nutational energy into spin energy, damping nutational amplitude.

A DESIGN TEST

A very interesting criterion has been found recently for the nature of the stable conditions of the top with two diametrically opposed pendulums; and, as will be seen, for space vehicles a certain combination of design parameters is definitely to be avoided.

It was first observed that the top, when fitted with a particularly long but well balanced pair of pendulums, damped quickly to a constant or stable amplitude (apparently) of nutation. However, when this performance was viewed under the stroboscopic light it was found that the two pendulum arms had finally assumed an attitude in which the angle between them was not 180° (Fig. 6). The resulting unbalance caused the assembly to rotate, stably, about an axis at an angle to the shaft of the top. The true nutation angle had damped to zero but there was a new principal axis, not the shaft of the top, about which final rotation occurred.

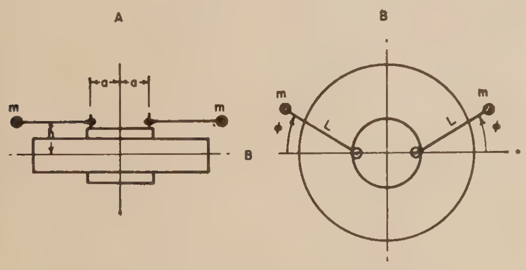


Fig. 6—Twin pendulums at angle ϕ.

This phenomenon was studied and the results are reported by Haseltine.[12] Instead of a detailed attack on the motion of the coupled rigid bodies, general energy arguments are used. It is demonstrated that there exists a minimum energy state and that this occurs when the pendulums are in a fixed attitude relative to the top. Under the conditions for this fixed attitude, it is shown that the assembly must rotate about the axis of greatest moment of inertia. Further, under this condition and for certain combinations of the design parameters, the pendulums will be deflected toward each other as actually observed with the top.

An approximate expression is derived for $\cos\phi$ where ϕ is the angle that each pendulum deviates from the diameter (extended) through the supporting pegs (Fig. 6). It is

$$\cos\phi = \text{the lesser of 1 or} \left(\frac{a(A-B)}{2mh^2L}\right),$$

where

a = distance from the top axis to the pendulum supporting pegs,
m = mass of one pendulum bob,
h = distance from center of gravity of the top to the plane of the pendulum supports,
L = length of the pendulum, and
A, B = respectively, the polar and transverse moments of inertia of the top.

It has been noted that if we know by experiment, or otherwise, that this stable condition of off-axis weights can exist, a simple derivation of the formula for the angles, ϕ, is possible. In Fig. 7 note that the two pendulums fall on lines crossing at the stable axis of rotation, A', as they must, since centrifugal force holds them in this position. The center of gravity (cg) of the two bobs falls at the point noted by $2m$ which is the distance h along the axis A, from the cg of the top and a distance ($L \sin\phi$) away from that axis. The rotation, θ, of the principal axis of inertia as the result of this mass is, approximately

$$\tan 2\theta = 2\,\frac{(\text{mass} \times d_1 \times d_2)}{(A-B)} = 2\,\frac{2mhL\sin\phi}{(A-B)}\,.$$

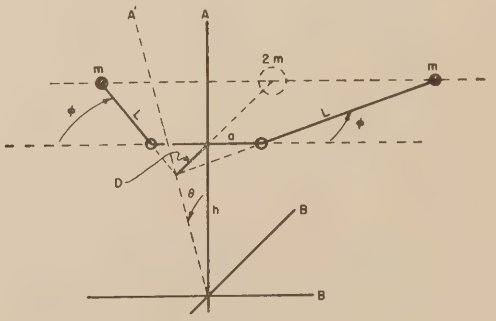


Fig. 7—Twin pendulums, cos ϕ derivation.

If θ is small, the factor 2 can be cancelled.

Multiplying $\tan\theta$ by h gives the distance, D, in Fig. 7, which can also be obtained by

$$D = a\tan\phi.$$

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[12] W. R. Haseltine, "Passive Damping of Wobbling Satellites," U. S. Naval Ord. Test Sta., China Lake, Calif., NOTS 2306 NAVORD 6579. (In press.)

The following can now be written:

$$D = h \tan \theta = a \tan \phi = \frac{2mh^2 L \sin \phi}{(A - B)}$$

or cancelling $\sin \phi$ from the last two and solving for $\cos \phi$,

$$\cos \phi = \frac{a(A - B)}{2mh^2 L},$$

as before.

It is quite evident that vehicle design should keep this expression for $\cos \phi$ comfortably greater than unity. For, even though we might devise a way to insure that the pendulums always go to the same side of the axis, A, so that we would know where A' will fall and design accordingly, the angle ϕ would be sensitive to changes in the design parameters and probably would not be very stable.

We therefore have a criterion for conditions to avoid in designing rotating space vehicles with pendulum dampers. Also, this development may serve as a warning that a similar situation might arise for other nutation damping schemes. It has, in fact, been shown that a similar condition can occur when four equal weights are used instead of two. The condition for good behavior is then similar but slightly more stringent.

Measurement of the Doppler Shift of Radio Transmissions from Satellites*

GEORGE C. WEIFFENBACH†

Summary—**This paper describes a receiving station network that was designed to produce Doppler data for use in a satellite Doppler navigation system. As a result of practical exigencies, this equipment is not optimum for its intended purpose, and a continuous effort is being maintained to improve the system. Current and projected changes are described briefly. Some experimental results obtained with the present system are presented.**

I. INTRODUCTION

THE function of the system which is described herein is to measure the Doppler shift of radio signals broadcast from a satellite. In particular, this system must detect the satellite transmissions, measure their frequency as a function of time, and reduce these measurements to a form suitable for transmission to a central computer. A previous paper[1] outlines the over-all navigation system of which the receiving station complex is one part.

The configuration of the receiving stations used for tracking is governed by the navigation system requirement for real time predictions of satellite positions to very high accuracies. Present ignorance of the geoid plus the accumulation of errors in digital computers will prevent, initially, the extrapolation of even an exact present orbit for more than a day or two into the future without a significant loss of accuracy. (Note that this is independent of the particular kind of observational data that was used to obtain the "present" orbit.) This fact necessitates the acquisition of dense sets of accurate data; *i.e.*, in a time which is substantially less than the "extrapolation time" of one day, one must accumulate observational data of sufficient quantity and quality that a very accurate present orbit may be computed. Furthermore, if a true real time *prediction* of satellite position is to be made (the only kind that is of interest in an operational navigation system), this data must be reduced and transmitted to the computing center in a time which is short with respect to the "extrapolation time." For these reasons it was decided that the data gathering or receiving station network must necessarily be capable of accurate and automatic reduction of the Doppler shift information to digital form. It must be automatic so that large quantities of data can be handled quickly and without serious error; digital so that it can be transmitted rapidly and without significant degradation.

The configuration of the navigation station depends on the accuracy required, with optimum performance necessitating instrumentation roughly equivalent to that used in the tracking stations.

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* Original manuscript received by the IRE, December 2, 1959. This work was supported by the Department of the Navy, Bureau of Ordnance, under Contract NOrd 7386.

† Applied Physics Laboratory, The Johns Hopkins University, Silver Spring, Md.

[1] W. H. Guier and G. C. Weiffenbach, "A satellite Doppler navigation system," this issue, p. 507.

II. Description of Tracking Station

Fig. 1 is a flow diagram of the apparatus that has been assembled to meet the above requirements. During the pass of an appropriate satellite, one can feed the signal from an antenna into one end of the equipment and simultaneously extract from the other end a strip of TWX tape containing an accurate description of the Doppler shift of the satellite transmission as a function of time.

Fig. 2 illustrates the receiving section, which consists of an antenna and a commercial receiver (Nems-Clarke Model 2501) and a phase-locked tracking filter (Interstate Electronics Model IVA). The function of this section is to pick up the weak satellite signals, amplify them, separate them from noise, and subtract from them an accurately known frequency (the "reference" or "injection" frequency) so that they form an appropriate input to the data reduction unit. It has been determined that the present equipment can perform this function satisfactorily with an input signal somewhat less than 0.02 microvolt, and indeed, using a simple vertical half wave antenna, successful operation has been obtained in observing the 10-mw 108-mc transmitter of 59 η whenever it was above the horizon.

Fig. 3 illustrates the time and frequency reference unit, which generates a local time base and a set of standard frequencies. The time is used to indicate when a particular Doppler measurement was made. The standard frequencies are used for the receiver injection frequency, for a tape recorder reference, and for the "meter frequency" which is used to measure the Doppler period in the data reduction unit. It is clearly necessary that a common time and frequency base be used throughout the navigational system. The most convenient method of accomplishing this is to synchronize the local references to the standard time and frequency broadcasts of the National Bureau of Standards WWV. (As pointed out previously,[1] the navigational satellite itself could be used to "transport" WWV or any other suitable time standard to any point on the globe, by transmitting time pulses plus correction data from the satellite at intervals of perhaps one minute.) The "missing pulse" detector is used to start the local clocks at the first second marker after the missing pulse in the WWV transmission. Corrections are made thereafter by adding or subtracting 1 mc cycles (μsec) with the motor-driven phase shifter. The continuously changing propagation paths of WWV transmissions preclude direct frequency comparisons of sufficient accuracy. The long term drift is monitored by observing deviations of the time base relative to WWV over a period which is long enough to average out all effects of propagation variations. A second frequency standard is maintained at each station to provide a short-term (seconds to minutes) monitor of local frequencies.

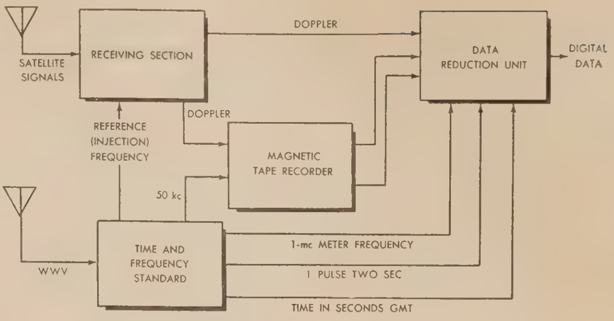
SATELLITE SIGNALS
RECEIVING SECTION
DOPPLER
DATA REDUCTION UNIT
DIGITAL DATA
REFERENCE (INJECTION) FREQUENCY
DOPPLER
MAGNETIC TAPE RECORDER
50 kc
WWV
TIME AND FREQUENCY STANDARD
1-mc METER FREQUENCY
1 PULSE TWO SEC
TIME IN SECONDS GMT

Fig. 1—Over-all flow diagram for receiving stations.

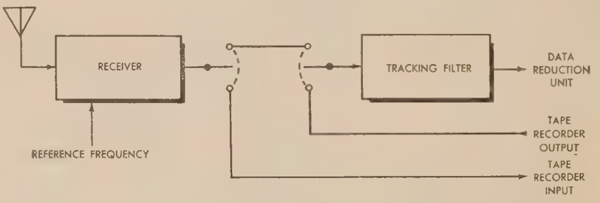
RECEIVER
REFERENCE FREQUENCY
TRACKING FILTER
DATA REDUCTION UNIT
TAPE RECORDER OUTPUT
TAPE RECORDER INPUT

Fig. 2—Simplified flow diagram for receiving section.

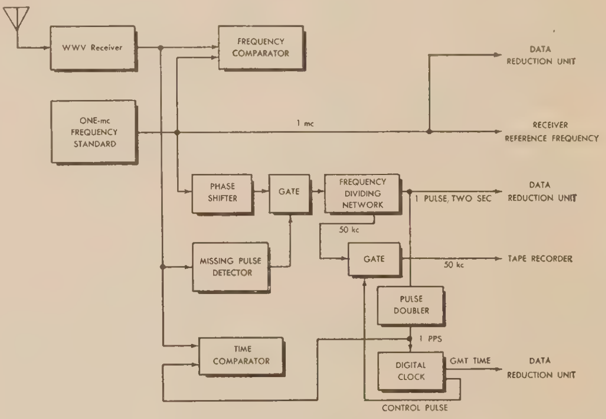
WWV Receiver
FREQUENCY COMPARATOR
DATA REDUCTION UNIT
ONE-mc FREQUENCY STANDARD
1 mc
RECEIVER REFERENCE FREQUENCY
PHASE SHIFTER
GATE
FREQUENCY DIVIDING NETWORK
1 PULSE, TWO SEC
DATA REDUCTION UNIT
50 kc
MISSING PULSE DETECTOR
GATE
50 kc
TAPE RECORDER
PULSE DOUBLER
1 PPS
TIME COMPARATOR
DIGITAL CLOCK
GMT TIME
DATA REDUCTION UNIT
CONTROL PULSE

Fig. 3—Simplified diagram of time and frequency reference unit.

The accuracies attained in the time and frequency units directly determine (together with satellite transmitter stability, etc.) the accuracy of the basic Doppler data. Table I lists the present estimates of the accuracies and stabilities needed to achieve a navigational accuracy of $\frac{1}{2}$ mile or better. All of the stipulated requirements are met in the present system using commercial components.

Fig. 4 illustrates the data reduction unit. Its function is to measure the Doppler frequency (actually it measures period), correlate it with time and punch the result on TWX paper tape. This is accomplished by the following sequence of events:

1) Timing pulse (1 pulse every 2 seconds) opens gate to preset counter.
2) Preset counter puts out gate-opening pulse at instant of first positive-going zero crossing of Doppler signal.

TABLE I

Reference frequency	Stability: 10^{-9}/seconds 10^{-9}/15 minutes Accuracy: 2×10^{-9}
Meter frequency	Stability: 10^{-7}/seconds 10^{-7}/15 minutes Accuracy: 2×10^{-7}
Clock	Stability: 10^{-6}/15 minutes Accuracy: 5 ms
Tape Recorder Reference (50 kc)	Stability: 10^{-7}/seconds 10^{-7}/15 minutes Accuracy: 2×10^{-7}

Time and frequency accuracy and stability requirements (based on assumption that WWV is exact). The U. S. Naval Observatory, and others, provide corrections to WWV broadcasts which are used in the navigation system central computing facility.

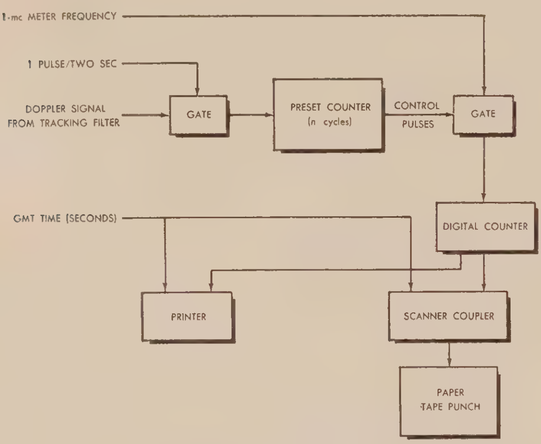

Fig. 4—Simplified diagram of data reduction unit.

3) Preset counter puts out gate-closing pulse at instant of n_cth positive-going zero crossing of Doppler signal.
4) Gate controlled by preset counter is open for duration T of n_c Doppler cycles. T is measured by observing the number of 1-mc cycles (μsec) that pass through gate. This number is registered on digital counter.
5) The scanner coupler then reads the time on the digital clock (in the time and frequency reference unit) and the meter frequency counter reading, and feeds these numbers serially to the paper tape punch.
6) The paper tape punch punches the appropriate set of numbers on paper tape.

The output of this section is an eleven digit number in which the first five digits indicate time in seconds after midnight GMT, and the last six digits indicate the period (in μsec) of the first n_c Doppler cycles following this time reading. The number n_c is selected so that T for the lowest expected value of the Doppler signal is less than, but nearly, one second. The scanning and readout take about 600 ms. One data point is obtained every two seconds. The only significant error introduced in this digitalizing process is the ± 1 count ($= \pm 1$ μsec) resolution of the meter frequency counter, which results in a frequency error of $\pm(f^2/n_c)\times10^{-6}$ cps, where f is the (audio) Doppler input to the preset counter.

Fig. 5 illustrates the magnetic tape recorder unit. This section provides storage for Doppler data pending availability of the data reduction unit and tracking filter, so that a receiving station with only one each of the latter can obtain data for a multifrequency satellite. The Doppler signals directly out of the receivers are recorded simultaneously with a 50-kc reference. A time reference is obtained by gating the 50 kc, *i.e.*, starting the 50 kc on the recording by means of a pulse from the real time clock. By counting down the 50 kc to 1 pulse per second and feeding this into a prefilled (playback) clock the latter will operate in synchronism with the original clock readings at the time the Doppler was recorded. By multiplying the 50 kc up to 1 mc for use as the meter frequency, the effects of variable tape speed, from record through playback, should be removed.

One additional unit is planned but is not in operation at the present time. This is the analog refraction correction unit shown in Fig. 6. This unit makes use of the known dispersion properties of ionospheric refraction, *i.e.*, that the effective index of refraction of the ionosphere, n, is given to first approximation by the formula[1]

$$n = \sqrt{1 - f_N^2/f_i^2}$$

where

$f_N =$ plasma frequency $= \sqrt{Ne^2/\pi m}$
$N =$ electron density in electrons/cc
$e =$ electronic charge in esu
$m =$ electron mass in grams
$f_i =$ transmitter frequency.

Using this relationship, the observed Doppler shift can be approximated by a power series in $1/f_i$ as[1]

$$\Delta f^{(i)}(t) = \Delta f_0^{(i)}(t) + \Delta f_1^{(i)}(t) \tag{1}$$

where

$\Delta f^{(i)}(t) =$ Doppler shift of f_i as received,
$\Delta f_0^{(i)}(t) =$ "vacuum" Doppler shift, *i.e.*, as it would be in absence of ionosphere,
$\Delta f_0^{(i)}(t) = f_i \Delta f_0^{(0)}(t) = f_i \dot{\rho}(t)/c$,
$\dot{\rho}(t) =$ time rate of change of slant range from ground station to satellite,
$c =$ vacuum velocity of light,
$\Delta f_1^{(i)}(t) =$ first order "error term" resulting from ionospheric effects,
$\Delta f_1^{(i)}(t) = \alpha(t)/f_i$
$\alpha(t) =$ power series coefficient for $1/f_i$ term.

Since $\Delta f_0^{(0)}(t)$ and $\alpha(t)$ are independent of frequency, (1) can be used in conjunction with measurements of $\Delta f^{(i)}(t)$ at two frequencies to construct two simultaneous equations that can be solved for $\Delta f_0^{(0)}(t)$ or $\alpha(t)$ by

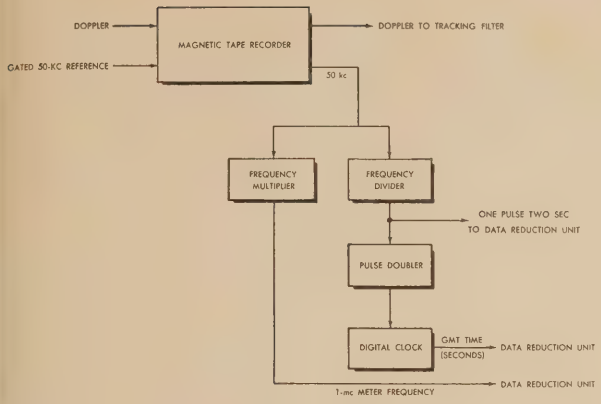
DOPPLER
GATED 50-KC REFERENCE
MAGNETIC TAPE RECORDER
DOPPLER TO TRACKING FILTER
50 kc
FREQUENCY MULTIPLIER
FREQUENCY DIVIDER
ONE PULSE TWO SEC TO DATA REDUCTION UNIT
PULSE DOUBLER
DIGITAL CLOCK
GMT TIME (SECONDS)
DATA REDUCTION UNIT
1-mc METER FREQUENCY
DATA REDUCTION UNIT

Fig. 5—Simplified diagram of magnetic tape recorder unit.

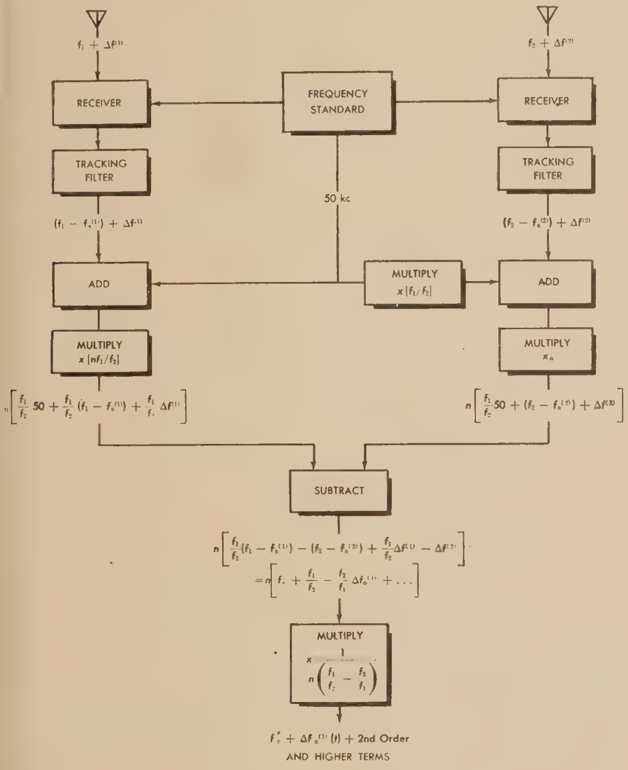
$f_1 + \Delta f^{(1)}$
$f_2 + \Delta f^{(2)}$
RECEIVER
FREQUENCY STANDARD
RECEIVER
TRACKING FILTER
TRACKING FILTER
50 kc
$(f_1 - f_0^{(1)}) + \Delta f^{(1)}$
$(f_2 - f_0^{(2)}) + \Delta f^{(2)}$
ADD
MULTIPLY $x\,[f_1/f_2]$
ADD
MULTIPLY $x\,[nf_1/f_2]$
MULTIPLY x_n
$n\left[\frac{f_1}{f_2}50 + \frac{f_1}{f_2}(f_1 - f_0^{(1)}) + \frac{f_1}{f_2}\Delta f^{(1)}\right]$
$n\left[\frac{f_1}{f_2}50 + (f_2 - f_0^{(2)}) + \Delta f^{(2)}\right]$
SUBTRACT
$n\left[\frac{f_1}{f_2}(f_1 - f_0^{(1)}) - (f_2 - f_0^{(2)}) + \frac{f_1}{f_2}\Delta f^{(1)} - \Delta f^{(2)}\right]$
$= n\left[f_c + \frac{f_1}{f_2} - \frac{f_2}{f_1}\Delta f_0^{(1)} + \dots\right]$
MULTIPLY $x\,\frac{1}{n\left(\frac{f_1}{f_2} - \frac{f_2}{f_1}\right)}$
$f_c' + \Delta f_0^{(1)}(t) +$ 2nd Order AND HIGHER TERMS

Fig. 6—Analog instrumentation for extracting $f_0^{(1)}(t)$, the "unrefracted" Doppler shift for the satellite transmitter frequency f_1. The two satellite transmitter frequencies, f_1 and f_2, should be coherent. (Note: $f_{c'}$ is a known constant. The final multiplication is done in the central computer.)

elimination. The instrumentation shown in Fig. 6 will perform this elimination to produce $\Delta f_0^{(i)}(t)$, the "vacuum" Doppler. If the approximations are sufficiently accurate, this will provide refraction-free data for the computer. Note that when f_1 is the second harmonic of f_2, for example, all of the operations shown in the figure can be performed with standard circuits.

The instrumentation described in the preceding section constitutes a tracking station for the present satellite navigation system. Clearly, any one of these stations can function as a navigating station simply by using its output data for computing a navigational fix instead of sending the data to the central computer for use in orbit determination.

III. Present Tracking Station System

At the time of this writing, five receiving stations, each as described in Section II, have been assembled to form a system whose function is to gather the data for precision tracking of a navigational satellite. These stations are located in Howard County, Maryland; Argentia, Newfoundland; Seattle, Washington; the Defense Research Laboratory of the University of Texas, Austin, Texas; and the Physical Sciences Laboratory of the New Mexico State University, Las Cruces, New Mexico. A sixth installation which is only instrumented to produce magnetic tape for reduction at one of the complete stations is currently operated by the Radio Department of the Royal Aircraft Establishment at Lasham, England.

It is hoped that it will be possible to enlarge this network to provide more extensive geographic coverage, which is necessary to realize the full potential of the system to produce accurate ephemerides. The present locations were selected to provide a "hard core" of stations which would not get entangled in acute logistic and communications problems, but would, nonetheless, cover a reasonably wide area. It has been possible to transmit all data by commercial TWX, and only at Argentia has it been necessary to use a leased line.

IV. Comments

The equipment described above has functioned satisfactorily in that it has produced data in actual practice that is sufficiently accurate for orbit determination. However, it is not optimum in all respects. For instance, it would be an improvement to replace the conventional second detector in the receiver with a synchronous detector, or, even better, to remove this detector completely. This could be accomplished by locking the local oscillators in the receiver to the frequency standard. By a suitable choice of local oscillator frequencies, the "difference" frequency at the receiver output could be adjusted to fall within the tuning range of the tracking filter. The net result of this change would be to improve the S/N capability of the receiving system by at least 3 db.

Another modification that may be useful would be to place the present tracking filter, which operates at a relatively low frequency, with an RF servo loop similar to that used in the Microlock system. This would provide some added flexibility by increasing the tuning range of the tracking loop. It may also reduce costs. It is not clear, however, which approach produces the better results. Plans are now being formulated to compare the amount of phase jitter in the voltage controlled oscillators used in each system, and these results will probably be the most important factor in determining which method is to be used.

Other changes that are being considered are adjustment of the "counting time" over which each measurement is made. It will probably be increased, the extent of the change depending on the outcome of error analyses which are planned. Also some revisions of the magnetic tape operation are being studied, because "high" frequency flutter components (>50 cps) have prevented the tracking filters from following the Doppler signal in playback as closely as is desired.

Considerable thought is being given to the development of equipment engineered specifically for this purpose. This will be especially important for navigational instruments where reliability, size, weight, cost, and power requirements will be critical. The first thought that arises in this connection is that the operational equipment must be transistorized and modular.

It is expected that experience will decide the best answers to the above questions, and will certainly dictate the detailed form of equipment for each specific application of a satellite Doppler navigation system.

V. ACKNOWLEDGMENT

The basic idea of making Doppler measurements in the manner described was first developed by a group headed by L. G. DeBey at the Ballistic Research Laboratories, Aberdeen Proving Grounds, Md. It is a pleasure to acknowledge the help the Applied Physcis Laboratory has received from DeBey and his staff.

The physical equipment that actually constitutes a Doppler receiving station is much more complex than the brief description given here would indicate. Needless to say, innumerable problems had to be solved before the individual components could function smoothly as a practical operational unit. It is not possible to list all of the people at this laboratory who contributed to the success of this project. However, the author would like to mention, in particular, the work done by H. H. Elliott who designed many of the special circuits, *e.g.*, the Doppler preset counter and gates, and who was responsible for solving many perplexing practical problems in making the various units operate in unison.

Applications of Doppler Measurements to Problems in Relativity, Space Probe Tracking, and Geodesy*

ROBERT R. NEWTON†

Summary—**This paper begins with a discussion of the precision with which the Doppler shift in the signal received from a space vehicle can be measured, using existing atomic frequency standards on the ground, and a proposed transponder system on the vehicle. Applications of Doppler methods to measuring the gravitational redshift, to tracking space probes and measuring certain astronomical constants, and to geodesy, making use of the precision of atomic standards, are then presented. The conclusion drawn is that Doppler methods can improve upon existing accuracy in these areas.**

INTRODUCTION

GUIER and Weiffenbach[1] have described the general way in which Doppler signals from a near Earth satellite can be used either to determine the satellite orbit or to fix the position of the receiving station. Newton[2] has described how the same general method can be extended to the Doppler tracking of an interplanetary vehicle. This paper will describe some possible further extensions of the method.

Let us first point out what seems to be the central feature of the method, namely, that we attempt to use all of the information contained in the Doppler signal from a moving transmitter. This is quite different from another method frequently used in the Doppler tracking of satellites, in which the Doppler is used only to yield the time and range at nearest approach to the receiver (and sometimes the speed).[3]

While many uses of Doppler signals from space vehicles can be developed at the level of accuracy contemplated in the works cited,[1,2] the usefulness of the general method can clearly be enhanced by an increased level of accuracy. Accordingly, we shall first discuss a

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* Original manuscript received by the IRE, December 2, 1959. This work was supported by the Department of the Navy, Bureau of Ordnance, under Contract NOrd 7386.

† Applied Physics Laboratory, The Johns Hopkins University, Silver Spring, Maryland.

[1] W. H. Guier and G. C. Weiffenbach, "A satellite Doppler navigation system," this issue, p. 507.

[2] R. R. Newton, "Tracking objects within the solar system using only Doppler measurements," in "1959 Proceedings of the Tenth Congress," International Astronautical Federation, London, in press.

[3] Incidentally, this method has often been misapplied: Let $\boldsymbol{\rho}$ be the vector from receiver to transmitter, with $\rho = |\boldsymbol{\rho}|$; then the classical Doppler frequency is proportional to $\dot{\rho} = \dot{\boldsymbol{\rho}} \cdot \boldsymbol{\rho}/\rho$. The minimum range is inferred from the derivative of this at the instant when $\dot{\rho} = 0$; the derivative of the Doppler at this instant is proportional to $\ddot{\rho} = (\ddot{\boldsymbol{\rho}} \cdot \boldsymbol{\rho} + \dot{\boldsymbol{\rho}} \cdot \dot{\boldsymbol{\rho}})/\rho$. It has been customary to neglect the first term in the numerator, thus making the assumption of unaccelerated motion, even though the first term can be quite appreciable. For example, with a satellite in a circular orbit at 700 km, at a minimum range of 800 km, the first term is about one-seventh of the second term.

method of exploiting the precision of atomic frequency standards. Following this, we shall discuss several applications: to measuring relativistic effects, to tracking interplanetary vehicles and concurrently improving astronomical data, and to making geodetic measurements.

USE OF ATOMIC STANDARDS IN DOPPLER APPLICATIONS

The most obvious way to use atomic frequency standards in space work is to place an atomic clock in the payload, and a program of developing an atomic clock to be flown in a satellite has been announced.[4] We shall describe an alternate method, which can probably be realized sooner and at less expense. This method is inferior in some applications to orbiting an atomic clock, and superior in others.

The alternate method is simple in principle. We start with an Earth-based transmitter, controlled in frequency by an atomic clock, which illuminates the space vehicle. The vehicle receives the signal, the frequency of which is now altered from the transmitted frequency by a Doppler shift, and phase-locks to it an on-board oscillator. The signal from the oscillator is then retransmitted, perhaps with a slight frequency shift for convenience, and the signal is received at an Earth-based station, again modified by Doppler. The resultant of the two Doppler shifts, one occurring with the outgoing signal, and one with the incoming signal, is then extracted by beating the final received frequency against an atomic standard.

There are several possible variants on this basic method. In some applications, we might want to have the Earth-based transmitter and receiver at different locations. This would require having two separate frequency standards, or else a reliable method of sending a standard frequency from one location to the other, and would limit the accuracy to the accuracy of the standards used, or to the accuracy in time and frequency of the ground communication link. In other applications, we would have the Earth-based transmitter and receiver at the same site. This would allow using only a single frequency standard, and it would limit the accuracy only by the frequency drift of the standard during the transit time of the radiation. For satellite work, the transit time would rarely exceed a quarter of a second, and the accuracy could be appreciably greater than the nominal accuracy of the frequency standard.

At this point, we should define more carefully what we mean by the accuracy of a frequency standard. We do not mean the accuracy with which the number of cycles per second of Ephemeris Time is known. If the standard is good enough to yield good Doppler data, then the precision in our knowledge of its absolute frequency is not a limiting factor. Also, we do not mean shifts in frequency which may occur over a few minutes of time. In the applications which we shall consider, observations will be made over a considerable period of time, long enough so that reasonable short-term fluctuations in frequency can be smoothed out statistically. What we do mean is the precision with which a transmitted frequency, averaged over perhaps an hour, can be compared with a received frequency, of almost equal value, and likewise averaged over perhaps an hour, with the precision expressed as a fractional part of one of the two frequencies compared.

With this definition of accuracy, we may expect the accuracy to be about 10^{-10} when different atomic standards are used for the transmitted and received frequencies, and considerably better than 10^{-10} when a single standard is used and when the transit time of the radiation is less than a second.

To analyze the meaning of accuracy in the latter case, let τ be the transit time of the radiation, and let $\epsilon(t)$ be the fractional deviation of the frequency standard at time t from its average over a long time. Then the error in measuring the Doppler frequency at time t is

$$\epsilon(t) - \epsilon(t - \tau) \approx \tau(d\epsilon/dt).$$

The significant quantity is the average (not the rms value) of this over some time interval, from 0 to T, for example. This average is

$$(\tau/T)[\epsilon(T) - \epsilon(0)].$$

The quantity in brackets will be of the order of 10^{-10} for an atomic standard, and τ/T can readily be of the order of 10^{-3}, so the accuracy for the case in question should be of the order of 10^{-13}. For a good crystal frequency standard, the corresponding accuracy should be better than 10^{-11}.

Another variant on the basic method concerns whether we have an almost constant frequency in the original transmission, or arrange to have an almost constant frequency in the signal received by the vehicle. If we know reasonably well, in advance of a particular experiment, the orbit of the vehicle and the location of the transmitter, we can alter the transmitted frequency by the amount of a predicted Doppler shift. In this way, the frequency received at the vehicle will vary only by the uncertainty in predicting the Doppler, and the stability of the transponder will be greatly enhanced. The price of doing this is a lowered stability in the original transmitted frequency; but it is probable that a net improvement can be effected, particularly when using a single standard for transmission and reception.[5]

Improved precision in frequency is, of course, meaningless unless the performance of all the other components in the system can be made compatible with the frequency performance. In particular, we must be able to measure accurately the time at which the Doppler frequency has a given value. The required precision in time is related to the maximum time derivative of the Doppler frequency. If ν is the transmitted frequency, and ρ is distance from receiver to transmitter, the time derivative of the Doppler frequency is $(\nu/c)\ddot{\rho}$. The time error δt compatible with an error, which we shall write as $\epsilon\nu$, in Doppler frequency is

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[4] For example, see the column "Miscellany" in *Physics Today*, vol. 12, p. 73; September, 1959.

[5] The general idea of using a transponder in a satellite to eliminate the on-board frequency standard must certainly have been suggested independently many times, although we are not aware of any references in the literature. The idea of modulating the transmitted frequency so as to keep the frequency constant at the satellite was suggested to the writer by L. J. Rueger of this Laboratory, and seems to us to have potentially great value.

$$\delta t = \epsilon\nu \div (\nu/c)\ddot{\rho} = \epsilon c/\ddot{\rho}.$$

The minimum δt required occurs when $\ddot{\rho}$ is a maximum. The value will clearly depend upon the application; to get a typical value, if $\ddot{\rho}=10$ m/second^2, and $\epsilon=10^{-11}$, $\delta t=3\times10^{-4}$ seconds. This precision is possible with the use of an atomic standard.

The most serious apparent problem in the way of utilizing the available precision is that of correcting the observed Doppler frequency for fluctuations in atmospheric and ionospheric refraction. While many people have reported large sporadic variations in the frequency received from a satellite, amounting sometimes to more than ten cycles at 100 mc, Weiffenbach[6] has observed signals in which such variations are certainly less than a few tenths of a cycle at 100 mc. If we can restrict the data used, for research purposes, to observing periods of such ionospheric quality, we may need to make the refraction corrections to an accuracy of only about one per cent. These corrections can perhaps be made by using more than one frequency, inferring the refraction from the measured dispersion, or by measuring the Faraday rotation and estimating refraction from the rotation.

MEASUREMENT OF RELATIVISTIC EFFECTS

For a near Earth satellite, $\dot{\rho}/c$ is of the order of 10^{-5}. Relativistic effects in the Doppler shift are of the order of $(\dot{\rho}/c)^2$ times the frequency, or $\nu\times10^{-10}$, where ν is the transmitted frequency. If the accuracy of measuring the Doppler frequency is $\epsilon\nu$, we cannot measure relativistic effects unless ϵ is appreciably less than 10^{-10}.

The most interesting relativistic effect is probably the gravitational red shift. Regardless of the accuracy available, the red shift cannot be measured by a transponder system, since the gravitational effect cancels on the outgoing and return legs. In order to measure the red shift, it is apparently necessary to have a stable transmitter on the satellite whose frequency is known in the satellite frame of reference.

Singer,[7] in his proposal for a measurement of the red shift, and Badessa, Kent, and Nowell,[8] in presenting an ingenious method of cancelling the first-order Doppler shift, apparently assume that an atomic standard, calibrated on the ground, will keep the same frequency, in local units, when satellite-borne. Considering the rigors of launching, and other uncertainties, it seems undesirable to have the accuracy of the experiment rest upon this assumption; it is better to arrange that the standard frequency be measured in flight, using a method which can separate measurement of the frequency from measurement of the red shift.

Accordingly, we suggest carrying a transponder system together with an atomic frequency standard in a satellite. Using the transponder system, we can determine the satellite orbit; the only assumption which this requires about the gravitational red shift is that the shift changes sign according to whether radiation is traveling with or against the field. With the orbit thus determined, study of the Doppler shift in radiation controlled by the atomic standard gives the combined effect of the red shift and a shift in the standard frequency. If the orbit is circular, both of these shifts are constant, and we cannot separate them; however, if the orbit is highly eccentric, we can hope to deduce the dependence of the total shift upon gravitational potential, and hence to separate the two effects.

INTERPLANETARY TRACKING AND ASTRONOMICAL DATA

In work previously cited,[2] the accuracy of tracking the early part of a space probe trajectory by Doppler methods has been estimated at about one part in 10^5 of the orbit parameters, at the end of about half a day of tracking. By going to atomic frequency standards, we can expect to increase the precision to about one part in 10^7 for short-term tracking, and probably better for long-term tracking.

Since the transit time of the radiation is large, the method of using a single frequency standard probably is no more accurate than a method using two standards, although it may be more convenient. It should still be advantageous to premodulate the signals so that the frequency at the space probe is nearly constant.

One result of increased precision should be an increased tracking range, by virtue of decreasing the bandwidth required: the bandwidth can be decreased, in principle, down to the uncertainty in the value of frequency to be received. If scintillations in frequency produced by refraction do not impose a larger limit, we can work at, for example, 0.01 cycle bandwidth at 100 mc, and thus increase the range, on a conservative basis, from 50 million kilometers to perhaps 500 million kilometers, for a few watts of transmitted power from the probe. Whether this limit can be reached in the presence of ionospheric noise remains to be seen.

If the precision in long-term tracking of a space probe can be increased to one part in 10^8 for the orbit elements, one result may be to eliminate the need for a separate midcourse navigation system on board a planetary probe. A Mars probe, for example, could be placed at a point near Mars with a precision of about two miles, accurate enough to start the re-entry phase of the trajectory without the need of an on-board system to track the planet up to this point. Because of the fast reactions required, if for no other reason, a separate system will presumably be needed from this point until the landing.

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[6] G. C. Weiffenbach, private communication.

[7] S. F. Singer, "Application of an artificial satellite to the measurement of the general relativistic 'red-shift'," *Phys. Rev.*, vol. 104, pp. 11–14; October 1, 1956.

[8] R. S. Badessa, R. L. Kent, and J. C. Nowell, "Short-time measurements of time dilation in an earth satellite," *Phys. Rev., Lett.*, vol. 3, pp. 79–80; July 15, 1959.

Another result of increased precision will be an improvement in the values of certain astronomical constants. All quantities which affect the motion of the vehicle, the motion of the observer, or the propagation of radiation between the two, affect the Doppler frequency. Thus, by measuring the Doppler, we can get a measure of these quantities, with an accuracy which depends upon the sensitivity of the Doppler to them, provided that we make enough measurements to separate out the different ways in which the different quantities affect the Doppler. Among such quantities will certainly be the mass ratios of Sun, Earth, and Moon, the values of their mean distances in terms of laboratory units of distance, and the velocity of light in interplanetary space. If the tracking extends over a few months in time, which is a significant part of the orbital periods of Mercury and Venus, we may even obtain improved values of their masses by analyzing perturbations upon the space probe orbit.

It is perhaps surprising that we can determine geodetic data of currently useful quality from tracking an interplanetary vehicle. However, the component of velocity which the receiving station has because it is carried upon the surface of the rotating Earth (and, consequently, its geocentric coordinates), enters directly into determining the Doppler shift. If the shift is measured to a precision of $\epsilon\nu$, the velocity is measured to a precision of ϵc, or about 0.003 m/second for $\epsilon = 10^{-11}$. Rotational velocity at the equator is about 460 m/second; thus, for a station at the equator, we can determine the local radius of the Earth and the east-west position of the receiver within about 40 m. This exceeds the present accuracy for some parts of the Earth.

It is important to realize, first, that these geodetic data are obtained from a system which is completely independent of any anomalies in the Earth's gravitational field (since it does not significantly depend upon Earth's gravitation at all), and, second, that the data obtained are directly the coordinates of the receiving station in the coordinate system whose origin is the terrestrial center of mass, and one of whose axes is the instantaneous axis of rotation of the Earth. Measurements made in this way are therefore independent of the traditional methods of geodesy, being based upon independent principles, and therefore can form a valuable supplement to geodetic data.

Geodetic measurements having this same advantage can, however, be obtained with greater accuracy using Doppler data from a high altitude Earth satellite. This brings us to a model for a geodetic satellite.

A GEODETIC SATELLITE

The figure of the Earth enters into determining the Doppler shift in the signal from a satellite in two independent ways. First, the figure, in conjunction with the density distribution, determines the gravitational field in which the satellite moves. Second, the figure, in a fashion which is purely geometrical and independent of the density distribution, determines the velocity of the receiving station, which is part of the relative veloctiy between transmitter and receiver. It is desirable to make geodetic measurements which separate these effects, perhaps by eliminating one of them.

Use of a space probe for geodetic work accomplishes this purpose by eliminating the effects of the Earth's gravitation, but at the expense of decreasing the sensitivity of Doppler measurements to the receiver coordinates. A near Earth satellite gives greater sensitivity to the coordinates, but at the expense of making the orbit sensitive both to local gravitational anomalies, including the time-dependent effects produced by tides, and to variations in drag.[9] A compromise is desirable: for geodesy we should use the lowest-altitude orbit which is unaffected, to the desired accuracy, by gravitational anomalies or by fluctuating drag, within the time period needed for the observations. This time will be of the order of a few orbital periods.

We do not know what the optimum altitude for this geodetic satellite should be. We shall assume that the altitude is one Earth radius; this altitude is unlikely to be too low, so that we shall be conservative in using this altitude when we estimate the accuracy of determining coordinates.

It is difficult to estimate the accuracy for a general orbit and a general observing position. We have made an estimate for the particular case of a circular equatorial orbit at an altitude of one Earth radius, and an observer near the equator. The method of calculation is similar to the standard method outlined, for example, by Newton,[2] except that we assume here that the mean value of the population from which a noise sample is drawn is not zero, but increases uniformly from zero to $2\epsilon\nu$ during a single pass. This puts both a drift and a bias into the observations of frequency. σ_R, the error in the local radius of the Earth, and σ_L, the error in longitude, become:

$$\sigma_R = 2 \times 10^{11}\epsilon \text{ meters},$$

$$\sigma_L = 5 \times 10^{11}\epsilon \text{ meters}.$$

The error in measuring latitude is approximately $\sigma_R \sec \theta_{\max}$, where $\theta_{\max}$ is the maximum elevation of the satellite during the pass. Unless $\theta_{\max}$ is too close to 90°, the error in latitude is comparable to σ_R.

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[9] D. G. King-Hele, "Determination of air density and earth's gravitational field from the orbits of artificial satellites," in "1959 Proceedings of the Tenth Congress," International Astronautical Federation, London, in press.

For $\epsilon = 10^{-11}$, then, we can find the geocentric coordinates of the observer to an accuracy of a few meters from a single pass, provided that accuracy is limited only by the accuracy with which a Doppler frequency can be measured. Since we can probably make $\epsilon < 10^{-11}$, and can use more than one pass, we can hope to measure coordinates to a meter or less, again with the assumption that the problems other than frequency measurement can be solved. We have already discussed some of these other problems.

In using this satellite, we shall probably find it helpful to use both the method of a single standard, with receiver and transmitter at the same location, and the method of separate locations. The former gives greater precision, but the latter yields the relative coordinates of transmitter and receiver directly, and should facilitate some studies. It should also be possible to make measurements from a surface vessel, although with some loss of accuracy, thus enormously increasing the geodetic coverage of the globe.

We should almost certainly use the method of modulating the originally transmitted frequency, in order to maintain constant frequency at the satellite.

It is, of course, desirable to make other accurate geodetic measurements using methods which involve gravitational anomalies, so that these anomalies can be studied.

ACKNOWLEDGMENT

The writer is grateful for helpful suggestions made by many of his colleagues at the Applied Physics Laboratory, particularly G. B. Bush and L. J. Rueger.

A Doppler-Cancellation Technique for Determining the Altitude Dependence of Gravitational Red Shift in an Earth Satellite*

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***Summary*—A cancellation technique permits measurement of the frequency of a source moving relative to an observer without the obscuring effect of first-order Doppler shifts. The application of this method to a gravitational red shift experiment involving the use of an earth satellite containing a highly stable oscillator is described. The rapidity with which a measurement can be made permits the taking of data at various altitudes in a given elliptical orbit. Tropospheric and ionospheric effects upon the accuracy of results are estimated.**

INTRODUCTION

ACCORDING to the General Theory of Relativity, the time kept by a "proper" clock (or the frequency of a standard oscillator) is affected by the motion of the clock and by its local gravitational potential. The latter effect, known as the "gravitational red shift," is expected to result in variations of only 7 parts in 10^{10} in the rates of clocks in the vicinity of the earth. Attempts to obtain experimental verification have been stimulated by the development of highly stable frequency standards and the availability of earth satellites in orbits that provide a significant variation in gravitational potential.

In 1956, Singer[1] proposed the measurement of gravitational red shift by an experiment involving comparison of the time kept by a stable clock in a satellite with that of an identical clock on earth. Since then, several versions of his experiment have been suggested. Basically, all of them involve the use of an atomic clock, or equivalent standard, from which, by frequency division, a series of precise timing pulses can be derived. These pulses would be transmitted as a modulated carrier over a one-way link from a satellite to earth, where they would be compared with a similar, locally generated timing waveform to determine the frequency difference. The frequency of the received pulses is directly influenced by the rate-of-change of path lengths (first-order or radial Doppler shift). This effect is typically four or five orders of magnitude larger than the gravita-

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* Original manuscript received by the IRE, November 23, 1959. This work was supported in part by the National Aeronautics and Space Administration under Contract NASw-33.

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[1] S. F. Singer, "Application of an artificial satellite to the measurement of the general relativistic 'red shift'," *Phys. Rev.*, vol. 104, pp. 11–14; October, 1956.

tional red shift. Consequently, data must be acquired over a sufficiently long time interval (probably several days) to insure that path-length measurement errors are negligible. At the completion of this experiment, a single value is obtained for the average frequency shift over many orbital periods. Thus it is not possible by this technique to determine the effect of altitude variations.

In order to obtain the altitude dependence of gravitational red shift, the measurement interval must be shortened to a small fraction of the orbital period. However, path-length variations make the performance of a short-time measurement in a one-way propagation experiment virtually impossible. But two-way propagation experiments offer definite possibilities. Engineers are quite familiar with the doubling of the first-order Doppler shift, which occurs in transmission of signals to and from a radar target. If it were possible to reverse the sense (*i.e.*, direction) of one of these frequency shifts by a mixing operation, then essentially complete cancellation of first-order Doppler shift could be effected. In the short-time measurement system[2] that will be described, such a technique permits data for a single altitude to be obtained in an interval of 60 seconds or less. The following significant advantages result.

1) By employing an elliptical orbit, frequency differences at various altitudes can be observed, and hence the variation of frequency with gravitational potential can be obtained.
2) If the measurement is repeated when the satellite is at a particular altitude (*e.g.*, at perigee), a slow frequency drift between satellite and earth clocks can be determined and removed. Since the quantity of interest is the *variation* in frequency difference as a function of altitude, a fixed offset frequency between clocks is inconsequential. Therefore, quartz-crystal oscillators can probably be employed.
3) Continuous integration or counting of pulses over many orbital periods is not required. Skipped cycles or temporary failures would not invalidate the experimental results.

The Short-Time Measurement Principle

The principle employed in a short-time measurement will be illustrated by a simplified analysis. In the interest of simplicity, the measurements are assumed to take place at an earth pole (*O* in Fig. 1). (An outline of the derivation of the following expressions is given in the Appendix.)

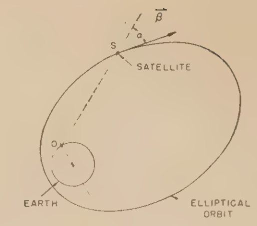

Fig. 1—Geometry of the measurement problem.

1) A transmitter (located at point *O*) of frequency f transmits to the satellite.
2) The frequency of the signal received at the satellite is

$$f' = f\frac{1-\beta\cos\alpha}{(1-\beta^2+2\phi)^{1/2}}, \tag{1}$$

where β is the magnitude of the satellite velocity (measured in the coordinate system of the observer at *O*) at the instant of reception, normalized in terms of the velocity of light; α is the angle (measured in the same coordinate system) between the propagation path *O–S* and the velocity vector $\vec{\beta}$; ϕ is the (positive) difference in gravitational potential between points *S* and *O*, normalized in terms of the square of the velocity of light.

3) The satellite contains an oscillator of frequency $2f$ (measured on the satellite). The received signal frequency f' is subtracted from $2f$ by mixing within the satellite to yield a frequency difference

$$f'' = 2f - f'. \tag{2}$$

4) The mixture signal f'' is transmitted back to earth. (Reception and retransmission at the satellite are assumed to be virtually instantaneous.)

The frequency of the received signal is measured as

$$f''' = f''\frac{(1-\beta^2+2\phi)^{1/2}}{1+\beta\cos\alpha}. \tag{3}$$

Substitution for f'' in (3) yields

$$f''' = f\left[2-\frac{1-\beta\cos\alpha}{(1-\beta^2+2\phi)^{1/2}}\right]\left[\frac{(1-\beta^2+2\phi)^{1/2}}{1+\beta\cos\alpha}\right]. \tag{4}$$

By means of a power-series expansion, retaining second-order terms in β and first-order terms in ϕ, we obtain

$$f''' \approx f(1+2\phi-\beta^2).$$

The first-order Doppler term has been cancelled, and the received signal frequency differs from the ground transmitter frequency by

$$\Delta f \approx f(2\phi-\beta^2). \tag{5}$$

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[2] R. S. Badessa, R. L. Kent, and J. C. Nowell, "Short-time measurement of time dilation in an earth satellite," *Phys. Rev. Lett.*, vol. 3, pp. 79–80; July, 1959.

The two terms in (5) are apparently inseparable experimentally. The first term, $2\phi f$, is the desired gravitational frequency shift. The second term, $-\beta^2 f$, is the well-known second-order, or transverse, Doppler shift of special relativity. This term, which has been verified experimentally, can be calculated easily and subtracted from the measured frequency difference to obtain the residual gravitational effect.

The frequency difference in the general case of an observer not located at the pole (Fig. 2) is given by

$$\Delta f = f[2\phi - (\beta_s^2 - \beta_0^2) - 2\beta_0\beta_s \cos(\alpha_2 + \gamma_2) - \beta_0^2(1 + r \sin \gamma_2)], \quad (6a)$$

where β_s, β_0, α_2, and γ_2 are as shown in Fig. 2, measured in a nonrotating coordinate system with origin at the earth's center and r is the range, normalized in terms of the earth's radius. The term in (6a) containing the product $\beta_0\beta_s$ is of the order of 10^{-10}, and cannot be neglected in the present experiment. This term must be retained, and appropriate values substituted. Present orbital computational accuracy is more than adequate for this purpose.

Satellite Equipment

As we have indicated, the operations to be performed in the satellite are as follows:

1) Amplify a received signal of frequency f'.
2) Mix the received signal with that of the satellite "clock" to obtain $2f-f'$.
3) Amplify and transmit a signal of frequency $2f-f'$.

In order for the cancellation of first-order Doppler shifts to be effective, the signals received and transmitted at the satellite must be very nearly of the same frequency. One way of avoiding the ensuing "spillover" problem is to employ pulsed waveforms. The received signal pulses, 1–10 μsec long, are stored briefly in a delay line or equivalent device. After the reception of each pulse, the receiver is turned off and the transmitter turned on. Fig. 3 is a block diagram of the satellite equipment required to instrument this technique. This configuration is intended only for purposes of illustration. An operating frequency range of 500–1000 mc, which is expected to fall between regions of severe ionospheric and tropospheric propagation anomalies, has been tentatively selected. A factor in the final choice of an operating frequency is the desirability of employing transistor circuitry. For ranges up to 10,000 miles, an RF output of approximately 20 mw (average), 0.4 watt (peak) is required from the satellite transmitter.

Although duplication of units is not indicated in the block diagram, it is particularly desirable to include more than one crystal frequency standard in the satellite, to permit independent measurements and to improve system reliability. The use of three crystal oscillators in a common temperature-stabilized oven is suggested. The crystals, which could be offset from one another in frequency for identification purposes, might be selected with different known temperature coefficients. Then variations in satellite temperature, which could possess a deceiving similarity to the orbital period of the satellite itself, will affect the three oscillators in varying degrees. Thus, a means for separating relativistic frequency shifts from temperature-dependent effects is provided. Preliminary power and weight estimates for the satellite equipment, including the weight estimate for batteries, are 3 watts and 35 pounds.

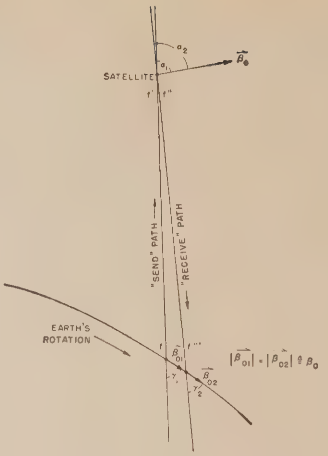

Fig. 2—Geometry of the two-way propagation experiment.

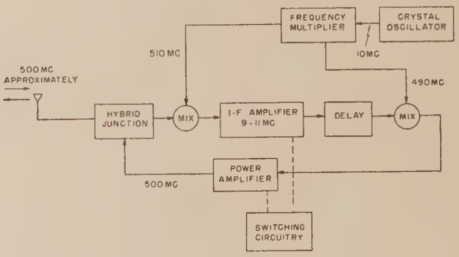

Fig. 3—Illustrative satellite-equipment configuration.

The stability of the crystal oscillators is of paramount importance and will be discussed separately. The overall phase shift through the receiver and transmitter should remain stable within 30° over the measurement interval 20–60 seconds, in order not to degrade the measurement accuracy which should be determined essentially by the short-term stability of the crystal oscillators.

Ground Equipment

An illustrative block diagram of the major portion of the required ground equipment is shown in Fig. 4. It functions as follows:

1) A signal of frequency f is transmitted.
2) A signal of frequency f''' is received from the satellite and compared in frequency with f by means of a mixer and a synchronous detector.
3) The frequency-difference signal is recorded on tape together with a fixed-frequency reference signal.

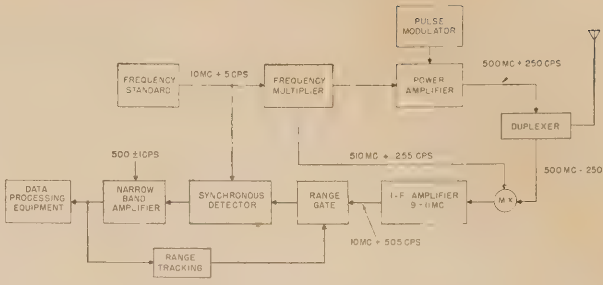

Fig. 4—Illustrative ground-equipment configuration.

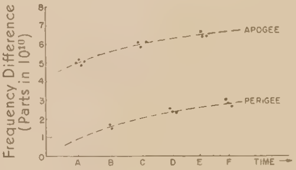

Fig. 5—Hypothetical data to illustrate oscillator stability requirements.

The transmitted and received signals both consist of series of pulses (each 1–10 μsec long). Time-delay discrimination is provided in the receiver for the rejection of transmitter feed-through signals and other undesired signals. In addition, a frequency offset of 1 part in 10^6 is purposely introduced between the ground and satellite frequency standards. This insures a small frequency separation between the signals transmitted and received on the ground, thereby facilitating resolution of the satellite signal from clutter by means of narrow-band filtering, without materially affecting first-order Doppler cancellation.

The coherent waveform and narrow-band filtering (±1 cps) employed in the ground receiver make possible the low requirement on satellite transmitter power (20 mw, average). Doppler tracking is unnecessary because the frequency of the signal received on the ground is virtually independent of first-order Doppler shift. However, the first-order Doppler shift is present in the signal received on the satellite. For simplicity, broad-band amplification, rather than Doppler tracking, is employed there, at the expense of increased ground-transmitter power. For a 10 meter^2 antenna on the ground, the power required to yield a clean signal on the satellite is approximately 500 watts (average), 10 kw (peak).

The ground station requires means for storage, as well as immediate processing, of the receiver output signal. The desired information is contained in the small variations in output frequency with orbital position. Since orbital position will be known as a function of time, a recording of the output signal together with a time signal will suffice.

Processing of the data involves measurement of a small frequency difference between two signals. This is best accomplished by measuring the total phase difference accumulated in a specific time interval. For example, a frequency difference of 0.1 cps in a 60-second interval results in a total accumulated phase difference of 2160°. This can be measured precisely by manual phase-tracking techniques, with the use of an oscilloscope as a visual tracking indicator.

OSCILLATOR STABILITY

The frequency standards used in this experiment must meet two separate stability requirements. First, all random and periodic frequency excursions must be at least an order of magnitude smaller than the total effect that is to be measured. Second, any long-term frequency drift in one orbital period should not exceed 20 to 30 per cent of the total desired effect. Perhaps the reasons for these stability requirements can best be illustrated by plotting a set of hypothetical data that might be obtained in this experiment. Fig. 5 shows a plot of the hypothetical frequency difference against time. For simplicity, it is assumed that data are acquired alternately at apogee and at perigee for several successive sightings. The clusters of points at times A, B, C, and so on, represent several readings of frequency difference obtained during the intervals when the satellite is visible. The frequency difference between the two dashed lines for apogee and perigee readings is expected to be approximately 4 parts in 10^{10}. Therefore, the undesired random and periodic frequency variations of the oscillators that are indicated by the dispersion of the clusters must be no greater than a few parts in 10^{11}.

The slope of either of the dashed lines in Fig. 5 represents the difference between the long-term drifts of the oscillators, and it is clear that a monotonic drift per orbital period of from 20 to 30 per cent of the total effect can easily be tolerated. For the proposed experiment, a drift of 1 part in 10^{10} in a few hours, or approximately 1 part in 10^9 per day, is permissible. A small fixed offset frequency between the oscillators would merely shift the base line in Fig. 5, and therefore would have no effect upon the desired measurement.

Actual measurements taken on commercially available quartz-crystal oscillators indicate that these oscillators essentially meet the stability requirements. Table I shows some data obtained in a comparison test. The 1-mc output signals of two crystal oscillators were multiplied up and mixed down in such a way as to magnify their frequency difference by a factor of 1000. The resulting beat frequency was then determined by means of a counter operating over periods of 10 and 100 seconds. The last digit of the counter output represents parts in 10^{10} for the 10-second count, and parts in 10^{11} for the 100-second count. In either case, the counter has a starting error of one count. Thus, the differences indicated between the two oscillators may be entirely accounted for by the counter error. The oscillator error is shown to be no greater than 1 part in 10^{11} when it is averaged over successive 100-second intervals.

TABLE I

Frequency Comparison Data for Two Hermes Model 101c 1-mc Crystal Frequency Standards

10-Second Counting Interval; Total Elapsed Time, Approximately 45 Minutes.	100-Second Counting Interval; Total Elapsed Time, Approximately 15 Minutes
93101	31005
93100	31006
93100	31006
93100	31005
93100	31006
.	31006
.	31006
.	
93100	
93100	
93101	
93100	
93101	

The oscillators that were tested employed vacuum-tube circuits; data are not available for a transistor version that is now being developed. However, the stability is believed to be determined primarily by the crystal and its oven, and not by the oscillator circuitry. Therefore no degradation in stability is expected to result from a change to transistors.

In order to transfer the oscillator stability to a transmitter operating in the UHF range, a chain of frequency multipliers is required. Two methods of frequency multiplication, both of which use variable-capacitance diodes as the multiplying elements, are being considered. Leeson and Weinreb,[3] in a detailed study of low-order frequency multipliers with nonlinear reactances, demonstrated that frequency doublers with only 1-db loss could be constructed. A chain of doublers that are now being developed to go from the oscillator frequency to the transmitter frequency is expected to yield a loss of only 10–15 db. The second approach to the frequency-multiplication problems is the use of one or two large frequency jumps. However, experimental results thus far indicate that in multiplying by a factor of 100, the loss is approximately 40 db.

Propagation Effects

As we have stated, the success of the described measurement depends upon the cancellation of the first-order Doppler shift, an effect that is four or five orders of magnitude greater than the gravitational red shift. For adequate cancellation, it is essential that random fluctuations in the effective path lengths upward and downward be small, or that they be well correlated. Phase fluctuations along the propagation paths are known to be caused by turbulent irregularities in the troposphere and in the F_2 region of the ionosphere. Extensive discussions of these and related effects have been published.[4–10]

It is desirable to select an operating frequency in a region in which the total rms phase error that is expected to arise from propagation anomalies falls well within the total permissible phase error of the experiment. If the frequency shift is computed by observing the total accumulated phase difference in a specified time interval T, then the resulting frequency error cannot exceed $\Delta\psi/\pi T$ cps, where $\Delta\psi$ is the total uncancelled phase fluctuation. At 500 mc, an rms phase error of 0.5 radian results in a 1 per cent error in frequency for a 60-second measurement interval. Such an error would be acceptable, since it is less than the value of the expected oscillator instability.

Tropospheric fine structure is measured by variations in the dielectric constant. The rms one-way phase fluctuation obtained by Muchmore and Wheelon[4] is given by

$$\psi_{\text{rms}} \approx \frac{(2l_0 L)^{1/2}\pi\Delta e}{\lambda}, \qquad \text{for } L \gg l_0, \tag{6b}$$

where l_0 represents the scale of the irregularities (probably 200 feet); L is the propagation path length through the turbulent medium (taken to be 20,000 feet); Δe is the rms deviation of the dielectric constant from unity (probably 10^{-6}); and λ is the wavelength. At a frequency of 1000 mc, the one-way phase fluctuation is computed as approximately 0.6° rms. This value is believed to be representative for a turbulent mass of (optically) clear air. In the presence of rain clouds, the interiors of which are very turbulent and contain large fluctuations in dielectric constant, the situation is somewhat different. If we take as representative values for a rain cloud $l_0 = 20$ feet, $L = 5000$ feet, $\Delta e = 20 \times 10^{-6}$, the one-way fluctuation in phase at 1000 mc is found to be approximately 1.6° rms. Thus, a net phase fluctuation of 2° or 3° rms might be typical for 1000-mc one-way propagation through the troposphere on a cloudy day.

The tropospheric phase-fluctuation measurements of Herbstreit and Thompson,[10] at 1046 mc, appear to be in general agreement with theory. The standard deviation of the phase shift over a 10-mile tropospheric path exceeded 3° fifty per cent of the time, and 5.5° ten per cent of the time. Moreover, the fluctuation period was found to be approximately 1 hour for large fluctuations, with minute-to-minute variations in phase shift of only 0.3° rms. Since the tropospheric phase fluctuation, from (6b), varies directly with the operating frequency, we conclude that the contribution of the troposphere to measurement errors in this experiment is negligible.

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[3] D. B. Leeson and S. Weinreb, "Frequency multiplication with nonlinear capacitors—a circuit analysis," Proc. IRE, vol. 47, p 2076–2084; December, 1959.

[4] R. B. Muchmore and A. D. Wheelon, "Line-of-sight propagation phenomena. I. Ray treatment," Proc. IRE, vol. 43, pp. 1437–1449; October, 1955.

[5] J. L. Pawsey and R. N. Bracewell, "Radio Astronomy," Clarendon Press, Oxford, Eng., pp. 347–351; 1955.

[6] H. G. Booker, "The use of radio stars to study irregular refraction of radio waves in the ionosphere," Proc. IRE, vol. 46, pp. 298–314; January, 1958.

[7] D. F. Martyn, "The normal F region of the ionosphere," Proc. IRE, vol. 47, pp. 147–155; February, 1959.

[8] C. O. Hines, "Motion in the ionosphere," Proc. IRE, vol. 47, pp. 176–186; February, 1959.

[9] "Propagation Factors Affecting Long-Range UHF Radars at High Latitudes," Defence Res. Telecommun. Establ., Ottawa, Ont., Can., Rept. No. 41-1-3; December, 1958.

[10] J. W. Herbstreit and M. E. Thompson, "Measurements of the phase of radio waves received over transmission paths with electrical lengths varying as a result of atmospheric turbulence," Proc. IRE, vol. 43, pp. 1391–1401; October, 1955.

Ionospheric fluctuations are measured by variations in the free-electron density. Turbulent irregularities in the F_2 region are maximum near midnight (local time) and occur in a region roughly 55 km thick at a nighttime altitude of approximately 300 km. The one-way rms phase fluctuation is shown by Booker[6] to be

$$\psi_{\text{rms}} = \left(\frac{h_0 H}{2}\right)^{1/2} r_e \lambda \Delta N, \tag{7}$$

where h_0, H are analogous to l_0, L for the troposphere (taken here to be 1 km and 55 km, respectively); r_e is the classical radius of the electron, 2.8×10^{-15} meter; and ΔN is the rms fluctuation in free-electron density. A value of $\Delta N = 10^{11}/\text{meter}^3$ is believed to be representative of the severe fluctuations encountered during periods of intense sunspot activity. Use of this value yields a phase fluctuation of 0.44 radian rms at 1000 mc. The ionospheric effect, from (7), varies inversely with the operating frequency. The desired relativistic effects, from (5), vary directly with frequency. Therefore, the fractional measurement error caused by ionospheric turbulence will vary inversely as the square of the operating frequency. Recent UHF measurements indicate that the phase fluctuation in propagation through the ionosphere is much less than one radian rms during a daytime period of normal ionospheric activity.

The Doppler-cancelling property of the two-way propagation experiment will effect cancellation of phase (or frequency) fluctuations resulting from propagation anomalies, as well as the radial Doppler shift resulting from the motion of the satellite, to the extent that correlation exists between the fluctuations introduced in the upward and downward traversals of the turbulent medium. The correlation coefficient is still to be estimated, in order to determine the residue of the calculated one-way phase fluctuation that will remain uncancelled in the experiment. It is known that the ionosphere rotates with the earth, and hence the upward- and downward-ray paths pass through essentially the same region of the ionosphere. The round-trip time delay, τ, associated with the largest anticipated range (10,000 miles) is 0.1 second. The value of the correlation coefficient for phase fluctuations displaced up to 0.1 second in time is therefore required. Experimental data[6,9] indicate maximum fluctuation rates of approximately 4 cycles per minute, occurring during periods of magnetic activity. Assuming an exponential correlation function, we have

$$\rho(\tau) = e^{-\omega_0 \tau}, \tag{8}$$

where $\omega_0 = 2\pi/15 = 0.42$ radian/second.

The residual (uncancelled) phase error is then given by

$$\Delta\psi_{\text{rms}} = \psi_{\text{rms}}[2(1 - \rho)]^{1/2} \tag{9}$$

which, for small values of $\omega_0\tau$, is approximately

$$\Delta\psi_{\text{rms}} \approx \psi_{\text{rms}}(2\omega_0\tau)^{1/2}, \qquad (\omega_0\tau \ll 1). \tag{10}$$

For $\tau = 0.1$ second, the quantity $(2\omega_0\tau)^{1/2}$ in (10) is equal to 1/3.5. The Doppler-cancellation process is therefore effective in reducing ionospheric phase fluctuations by a factor of 3.5, or better. The uncancelled phase shift is found to be 7.4° rms at 1000 mc, or 15° rms at 500 mc, for a path length (one-way) of 10,000 miles. Even at the lower operating frequency, the expected error for a 60-second measurement interval is only 0.0014 cps, or 0.4 per cent of the expected maximum red shift.

We conclude that for operating frequencies in the range 500–1000 mc, propagation anomalies will produce a negligible deterioration in the accuracy of the measurement.

APPENDIX

We shall outline a method for computation of the Doppler frequency shift associated with the propagation of electromagnetic signals between points in nonuniform motion in a gravitational field. An approximate result is derived here; an exact derivation has been made by Friedman.[11]

If a gravitational field in space is described in a system of coordinates x_1, x_2, x_3, x_4, where $x_4 = ct$, and t represents "coordinate time," then the relation

$$ds^2 = \sum_{\mu=1}^{4} \sum_{\nu=1}^{4} g_{\mu\nu} dx_\mu dx_\nu \tag{11}$$

holds between each locally measured interval ds and the corresponding coordinate differences, dx_μ. For events occurring at a single point, the locally measured interval is given by

$$ds = c d\tau, \tag{12}$$

where $d\tau$ denotes "proper time" at that point. The quantities $g_{\mu\nu}$ define the metric properties of space (*i.e.*, the gravitational field). For a spherically symmetric distribution of mass about the origin (Fig. 6), the $g_{\mu\nu}$ are given by the Schwarzschild solution to the field equations of general relativity:

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[11] M. H. Friedman, Dept. of Physics, M.I.T., Cambridge, Mass., private communication; October, 1959.

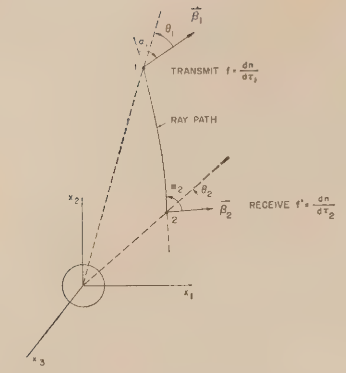

Fig. 6—Geometry of propagation between two points moving in a spherically symmetric gravitational field.

$$\begin{array}{ll} g_{44} = 1 + 2\phi & \\ \left.\begin{array}{l} g_{4\nu} = g_{\mu 4} = 0 \\ g_{\mu\nu} = -\,\delta_{\mu\nu} + \dfrac{2\phi}{1 + 2\phi}\,\dfrac{x_\mu x_\nu}{r^2} \end{array}\right\} & \begin{array}{l} \mu = 1, 2, 3 \\ \nu = 1, 2, 3, \end{array} \end{array} \tag{13}$$

where $\delta_{\mu\nu} = 1$ $(\mu = \nu)$; $\delta_{\mu\nu} = 0(\mu \neq \nu)$; r is the distance to the origin from the point x_1, x_2, x_3; and ϕ is the normalized gravitational potential at that point.

Consider a transmitter (Fig. 6) at point 1 in gravitational potential ϕ, whose frequency f is precisely controlled by a resonance of atoms, traveling with respect to the origin with (normalized) velocity β_1. The frequency transmitted may be regarded as some number of events per unit time. As viewed in the x_μ coordinate system, this frequency is given by

$$f_1 = \frac{dn}{dt_1} = \frac{dn}{d\tau_1}\,\frac{d\tau_1}{dt_1} = f\,\frac{d\tau_1}{dt_1}\,. \tag{14}$$

Substitution for $g_{\mu\nu}$ and ds in (11) yields

$$\frac{d\tau_1}{dt_1} = [1 + 2\phi_1 - \beta_1^2(1 - \epsilon_1 \cos^2 \theta_1)]^{1/2}, \tag{15}$$

in which $\epsilon_1 = (2\phi_1)/(1 + 2\phi_1)$; θ_1 is the angle between $\vec{\beta}_1$ and the radius to point 1. The observer at point 2 is assumed to utilize a frequency standard of like constitution to that at point 1. By the same method, the frequency received at point 2 (viewed in the x_μ coordinate system) can be related to the frequency measured. Thus

$$f_2 = f'\,\frac{d\tau_2}{dt_2} \tag{16}$$

and

$$\frac{d\tau_2}{dt_2} = [1 + 2\phi_2 - \beta_2^2(1 - \epsilon_2 \cos^2 \theta_2)]^{1/2}, \tag{17}$$

where dt_2 is the (coordinate) time of arrival of the ray at point 2. Since the number of events is preserved,

$$dn = f'\,\frac{d\tau_2}{dt_2}\,dt_2 = f\,\frac{d\tau_1}{dt_1}\,dt_1. \tag{18}$$

Therefore

$$f' = f\,\frac{dt_1}{dt_2}\left[\frac{1 + 2\phi_1 - \beta_1^2(1 - \epsilon_1 \cos^2 \theta_1)}{1 + 2\phi_2 - \beta_2^2(1 - \epsilon_2 \cos^2 \theta_2)}\right]^{1/2}. \tag{19}$$

The relationship between the coordinate times of reception and transmission is intractable because the ray velocity varies slightly along the path, and the path itself is curved. However, it can be shown that neglect of these effects leads to an error of the order of the satellite velocity multiplied by the gravitational potential, which is only approximately 10^{-14} for earth satellites. For present purposes, the derivation can be completed by a classical computation of the rate-of-change of path length:

$$\frac{dt_1}{dt_2} \approx \frac{1 - \beta_2 \cos \alpha_2}{1 + \beta_1 \cos \alpha_1}\,. \tag{20}$$

Moreover, ϵ_1 and ϵ_2 in (19) can be neglected. Thus,

$$f' \approx f\left[\frac{1 + 2\phi_1 - \beta_1^2}{1 + 2\phi_2 - \beta_2^2}\right]^{1/2}\left(\frac{1 - \beta_2 \cos \alpha_2}{1 + \beta_1 \cos \alpha_1}\right). \tag{21}$$

ACKNOWLEDGMENT

The authors wish to acknowledge the assistance given by Prof. M. H. Friedman, Prof. J. W. Graham, and V. J. Bates. They would also like to express their appreciation for the invaluable guidance of Prof. J. R. Zacharias.

Attitude Reference Devices for Space Vehicles*

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Summary—As the avenues of space travel broaden, the problem of determining the attitude of the space vehicle becomes more difficult; hence, the need for a compact, reliable sensing device is becoming increasingly important.

This paper presents the design features of an attitude sensing device which is quite compact and should prove to be reliable. The original objective in the design of the device was to provide a simple means of establishing a vertical reference line from an orbiting space vehicle to a planet under observation. It has been accomplished through the use of two narrow infrared scanning beams. The center line of each beam rotates at constant angular velocity in a plane, the plane of one beam being perpendicular to that of the other. The active portion of the scan is 270° for each beam. When the scanner intersects the planet, a step in the signal level occurs. Position of the beam when the half width of the signal step occurs establishes a plane which contains the center of the planet. Intersection of the two such planes generated by the dual scanner is the direction to the planet local vertical. The assembly is described in detail.

Further, by using analog computer techniques, it is shown that pitch and roll angles about this vertical reference line can be generated. A single degree of freedom gyro can be added to the equipment to produce yaw information in the case of an orbiting vehicle. Finally, a method for measuring altitude is discussed.

INTRODUCTION

As the avenues of space travel broaden, the problems associated with the control of the space vehicle become more complex, and at the same time of considerably more importance. The initial space vehicles have been fairly simple, with a limited amount of instrumentation aboard the vehicle and little importance attached to the orientation of the vehicle. In the succeeding months of this year, and in the years following, the attitude of the vehicle is going to be considerably more important, not only in knowing what it is, but also in being able to control it. For example, if we were photographing the earth from such a vehicle, it would be desirable to have the photographic device looking at the earth most of the time as the vehicle orbits.

The problem of attitude is complicated by a consideration of spinning vehicles. Quite often satellites are launched with a spinning motion applied to provide stabilization and insure a uniform thrust direction. In general, the spin velocity has not been too carefully controlled, but if a man is going to be aboard the vehicle, spin may be undesirable, or spinning at a predetermined, controlled rate may be highly desirable. In considering the problems of devising an attitude reference device which will be operative for spinning and nonspinning vehicles, a device has been chosen which will operate up to spin rates of 60 rpm. In addition, a range of altitudes of 150 to 600 nautical miles has been considered. Actually, higher altitudes could be accommodated by decreasing the beamwidth of the scanner. The vertical reference device described in this paper has been designed so as to require a minimum of space, and to be operative for extended periods of time, in fact for periods of time up to two years or longer. In keeping with the thought that the device should be useful for a broad range of vehicles, the design encompasses the measurement of several vehicle parameters, namely, roll, pitch and yaw about the local vertical, as well as altitude. The latter can be eliminated with a consequent improvement in size and weight. Yaw can also be eliminated with a still further improvement in size and weight. Actually, the requirements of the mission will dictate the amount of equipment to be used. The design is on a building-block basis to permit such utilization. Details of the equipment are described in the following pages.

HORIZON SENSING

Scanning is done by two narrow search beams operating simultaneously. The center line of each beam rotates at constant angular velocity in a plane, the plane of one being perpendicular to that of the other. These planes, hereafter referred to as scanning planes, are fixed, with respect to the vehicle axes, in a position such that their line of intersection coincides with the vehicle yaw axis (vertical reference line).

The manner in which the location of the local vertical is established is described by reference to Fig. 1, which

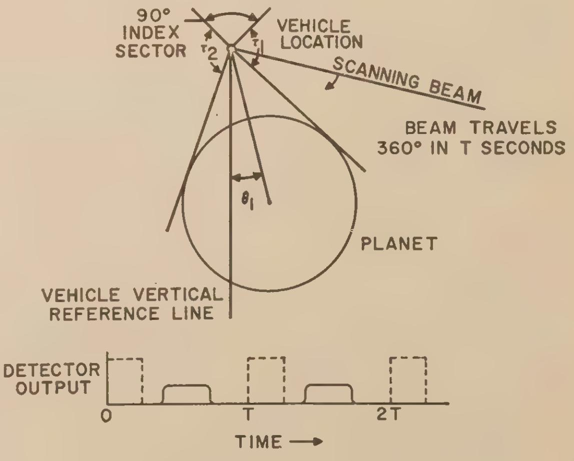

Fig. 1—Operation in one scanning plane.

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* Original manuscript received by the IRE, December 2, 1959. Paper presented at the National Aeronautical Electronics Conf., Dayton, Ohio, May 4, 1959.

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shows the geometry of a typical situation in one scanning plane. The cross section of the planet in the scanning plane, lines tangent to the cross section, the vehicle vertical reference line, and orientation of the index sector are shown to explain the appearance of the periodic waveform which is sketched in Fig. 1(b). Dotted pulses are shown for periods when the scanning beam is on the index sector. The index sector covers 90 degrees of scanner rotation and is centered about the vertical reference line, leaving a 270-degree sector in which the scanner can receive signals. Signal pulses, shown in solid lines, occur when the beam lies between the tangent lines.

Angle θ_1, the angle between the vehicle vertical reference line and the line from the vehicle to the center of the planet cross section, is the angle which we wish to find. It establishes the position of a plane which contains the planet center and which is situated perpendicular to the scanning plane. Another such plane is established by the second scanning beam, and the intersection of the two planes so established is the local vertical line.

It is obvious that

$$\theta_1 = \tfrac{1}{2}(\tau_2 - \tau_1). \tag{1}$$

Angles τ_1 and τ_2 are measured quantities, and angle θ_1 is computed in accordance with (1).

A train of fixed-amplitude rectangular pulses is generated so that the duration of the pulses is equal to the time required for the scanning beam to sweep through angle τ_1. Such a train can be generated by gating a voltage on at the trailing edge of the index pulse and gating it off at the leading edge of the signal pulse. (The index pulse is established by magnetic pickoffs on the scanning mechanism.) It is evident that

$$\overline{V}_1 = E\cdot\frac{\tau_1^\circ}{360^\circ}, \tag{2}$$

$\overline{V}_1$ = average value of the pulse train, and
E = amplitude of the pulses.

Another train of pulses of amplitude E is generated, each pulse having a duration equal to the time between the trailing edge of the signal pulse and the leading edge of the index pulse. Its average value is

$$\overline{V}_2 = E\cdot\frac{\tau_2^\circ}{360^\circ}. \tag{3}$$

Subtracting $\overline{V}_1$ from $\overline{V}_2$, we obtain a voltage proportional to θ_1. A similar process occurs in the signal channel associated with the other scanner, and a voltage is obtained which is proportional to an angle we will call θ_2, the angle defining the position of a second plane which contains the planet center.

It should be noted at this point that a voltage proportional to the angle subtended by the planet cross section can be derived by generating a similar train of pulses, each having a duration equal to that of the signal pulses. This angle will be used in computing vehicle altitude as shown in a later section.

Fig. 2 shows a sketch of the scanning assembly, in which two optical assemblies are driven at a continuous rate by the drive motor. In order to allow for vehicle spin rates of up to one revolution per second about an arbitrary axis, the optical assemblies are driven at 200 revolutions per second.

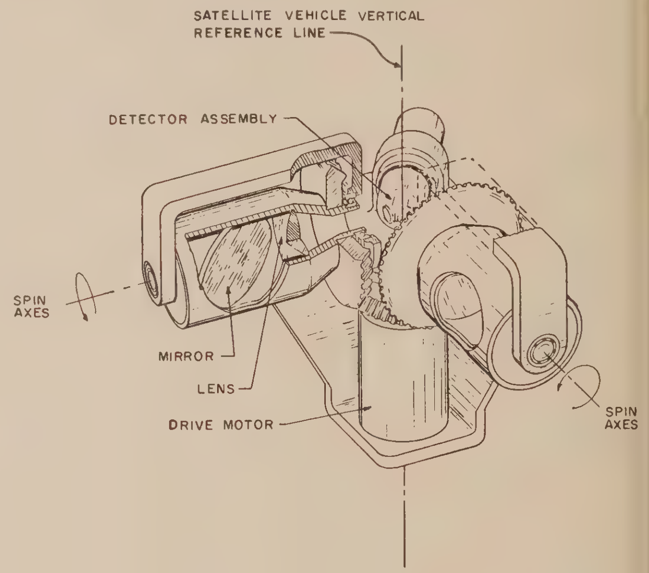


Fig. 2—Scanner assembly.

The optical system consists of a flat infrared-reflective mirror, a focussing lens, and a filter which attenuates radiation at wavelengths below 3 microns. It will serve to reduce direct solar radiation and minimize the effect of solar reflection gradients along the earth's surface. The focussing lens is a reflective doublet with an anti-reflection coating to give 94 per cent transmission at 4 microns.

Spectral distribution of radiation from the earth and atmosphere suggests a choice of operating wavelength greater than 3 microns. Because of the high scanning rate being used, the detector must have a relatively fast response time. In addition, it is desirable to use a detector which does not have to be cooled to liquid nitrogen temperature. Considering these requirements, an indium-antimonide detector (photoelectromagnetic type) was selected. A field of view of 2 degrees was chosen for the search beams. In order to achieve this condition with an optical system 1 inch in diameter and a focal length of 1½ inches, a detector area of 1 square millimeter is required; a reasonable value.

Carrying a coolant for the detector is impractical for flights of significant duration, and another means of cooling is necessary. Outside the atmosphere, it is possible to cool the detector by radiation into space. An emissive surface thermally connected to the detector will be used to radiate into space, but since the sun will illuminate the vehicle at times, it is necessary to provide highly reflective shutters to cover the portion of the radiating surface directed toward the sun. The shutters must, of course, operate automatically.

VERTICAL TRACKING

In order to measure vehicle yaw, one axis of a single-degree-of-freedom gyro must be maintained parallel with the earth's vertical. When this is done, the orbital angular velocity provides a torque on the gyro rotor, causing it to seek a position perpendicular to the orbital plane. A synchro pickoff within the gyro provides a yaw angle signal. (Note that the gyro must have 360 degrees of freedom.)

Fig. 3 is used to describe the angles required to position the gyro. Angles θ_1 and θ_2 have been defined previously as those measured from the vehicle yaw axis to planes containing the earth center. Angles θ_1 and ρ are the ones required to properly orient the gyro. Line OE is assigned a value of unity to simplify the calculation, and the other line lengths are labelled in terms of θ_1, θ_2, and ρ. Eq. (4) is obtained by inspection, noting that $\tan\theta_2 = CA/OA$.

$$\tan\rho = \tan\theta_2 \cdot \cos\theta_1. \tag{4}$$

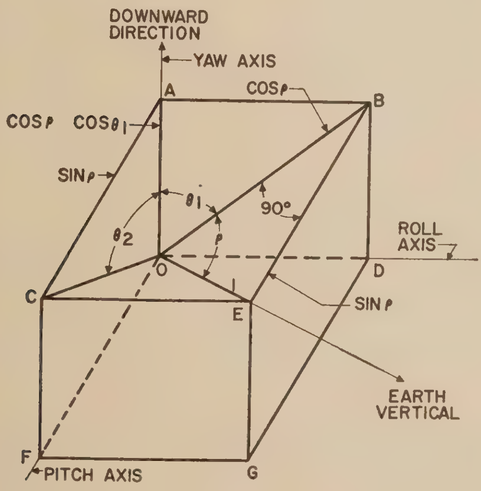


Fig. 3—Tracking angle relationships.

Voltages proportional to θ_1 and θ_2 are available from the detector channels and will be used to operate servo loops which maintain the gyro axis along the vertical. To accomplish this, a two-gimbal system is required with the gyro mounted on the inner gimbal. Fig. 4 shows a functional diagram of the servo loops.

Angle θ_1 and a conventional servo loop are used to position the outer gimbal. In addition to positioning the gimbal, the θ_1 servo positions a synchro for an output signal and operates a cosine potentiometer.

The dc signal proportional to θ_2 is altered by a shaping network to form $\tan\theta_2$, which is applied to the cosine potentiometer. The potentiometer output is a voltage proportional to the product $\tan\theta_2 \cos\theta_1$. Thus, the ρ servo generates a shaft position equal to ρ in accordance with (4). It drives a synchro to provide an output signal and positions the inner gimbal of the gimbal assembly.

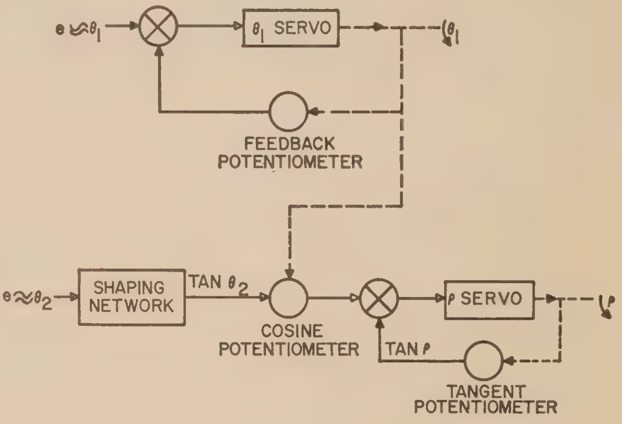


Fig. 4—Functional diagram of servo loops.

Use of a tangent feedback potentiometer in the servo loop at first appears impossible, since the tangent of 90 degrees is infinite; but when the value of either θ_1 or θ_2 is equal to or greater than 60 degrees, normal servo feedback loops are disconnected. A velocity memory loop is substituted so that the earth vertical is tracked even when there is no input from the scanners. The functional diagram of Fig. 5 shows the complete attitude reference system.

System response characteristics for yaw and pitch measurements are determined primarily by the servo loops. A tentative design of the servos was completed and the resulting loop for a representative case was simulated on an analog computer.

Required response time for both pitch and roll are assumed identical since the vehicle spin is taken to be in an arbitrary direction. Based upon that assumption, the roll servo presents the most difficult stability problem because of the nature of the feedback.

From an estimate of the weight and configuration of the load to be driven by the roll servo system, a load moment of inertia of 0.0025 slug-foot^2 was calculated. The motor selected to drive the load has the following parameters:

Rotor moment of inertia—	1.07 gm cm^2,
No-load speed—	6700 rpm, and
Stall torque—	0.63 oz-inch.

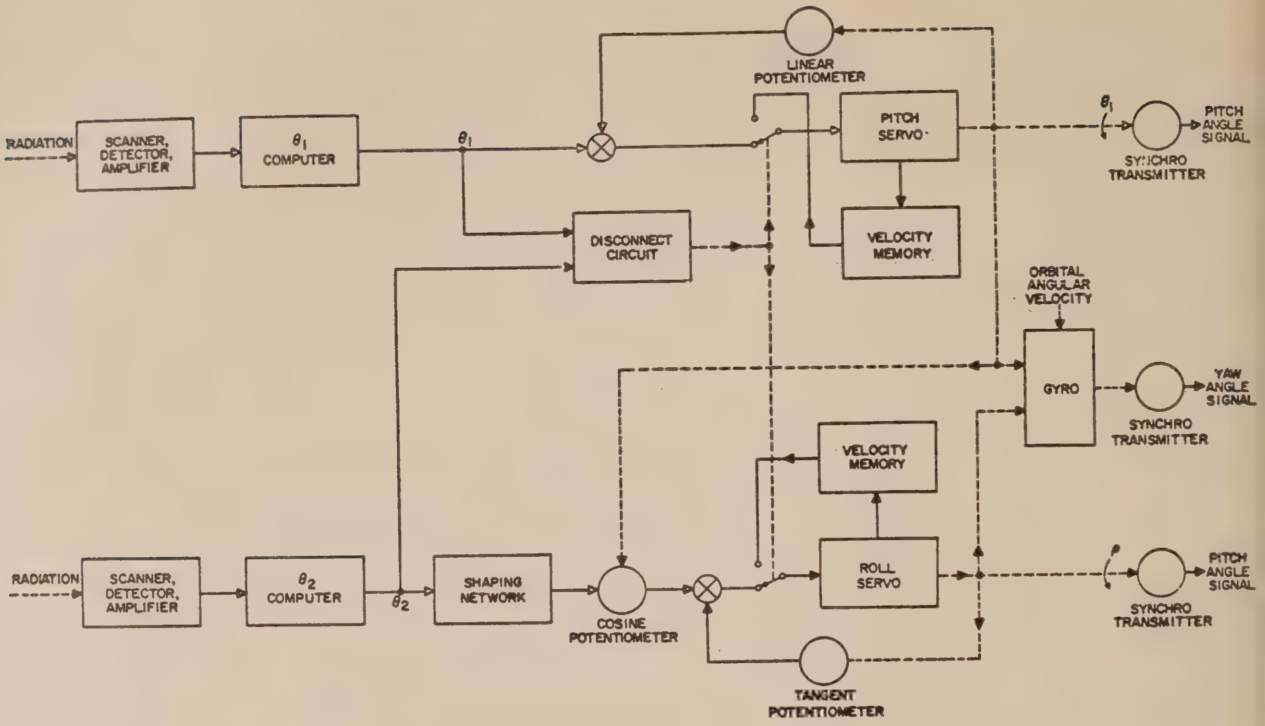

RADIATION
SCANNER, DETECTOR, AMPLIFIER
θ1 COMPUTER
θ1
LINEAR POTENTIOMETER
PITCH SERVO
DISCONNECT CIRCUIT
VELOCITY MEMORY
θ1
SYNCHRO TRANSMITTER
PITCH ANGLE SIGNAL
ORBITAL ANGULAR VELOCITY
GYRO
YAW ANGLE SIGNAL
SYNCHRO TRANSMITTER
VELOCITY MEMORY
ROLL SERVO
ρ
PITCH ANGLE SIGNAL
SYNCHRO TRANSMITTER
RADIATION
SCANNER, DETECTOR, AMPLIFIER
θ2 COMPUTER
θ2
SHAPING NETWORK
COSINE POTENTIOMETER
TANGENT POTENTIOMETER

Fig. 5—Functional diagram of attitude reference system.

Maximum angular velocity of the load was taken to be 50 rpm, and a gear ratio of 80:1 was chosen, making the maximum operating speed of the motor 4000 rpm. With this gear ratio, the moment of inertia of the motor reflected to the load is 0.0005 slug-foot². Neglecting viscous friction other than that provided by the motor, the reflected damping term is 0.03 pound-foot second per radian. The resulting transfer function for the motor and gear train neglecting the effect of coulomb friction is

$$\frac{\rho}{E_m}(s) = \frac{k_t}{Nf_m(0.1s + 1)} \tag{5}$$

where

ρ = output angle, radians,
N = gear ratio = 80,
f_m = motor damping coefficient = 4.7×10^{-6} lb-foot second/radian,
k_t = motor torque constant, lb-foot/volt, and
E_m = motor control winding voltage, volts.

$$G(s) = \frac{\rho}{E_e}(s) = \frac{\mathrm{Kv}(0.5s + 1)(0.02s + 1)}{s(0.1s + 1)(5s + 1)(0.002s + 1)} \tag{6}$$

where $E_e(s)$ is the transform of the error voltage.

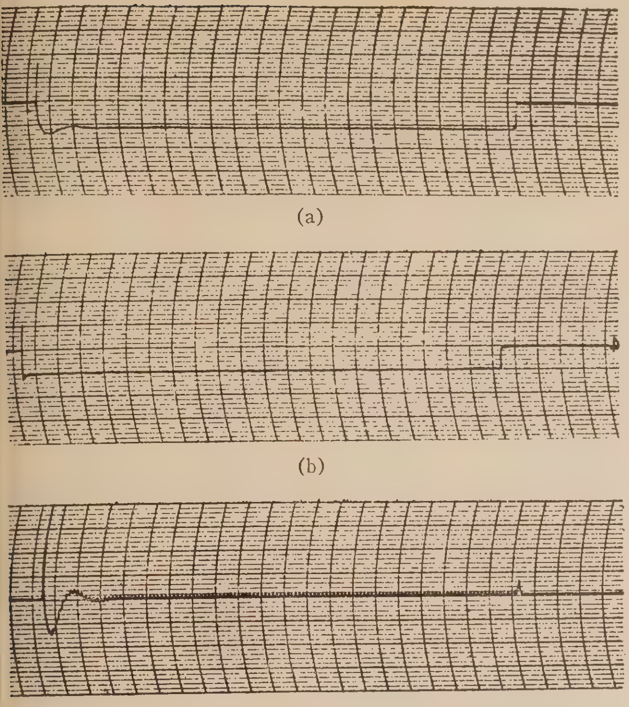
Closed-loop system response to a step input and to a ramp input is shown in Figs. 6 and 7, respectively. Kv was increased to 4800 for the recording in Fig. 8 to simulate the loop condition when ρ equals 60 degrees. The recording shows that the system is still stable.

ALTITUDE MEASUREMENT

In the system described here, the scanning planes do not, in general, intersect the earth center; hence the altitude cannot be calculated by using the subtended angle. Various methods for measuring altitude with the proposed system have been studied; the one which seems most desirable is described below. It should be noted that operation of the system relies upon satellite spin.

Angles θ_1 and θ_2 were described above. It is clear that if one of these angles, *e.g.*, θ_1, goes to zero, the scanning plane in which θ_2 lies must pass through the center of the earth. The magnitude of the angle subtended by the earth in the θ_2 plane at that time can be used to determine the vehicle altitude.

The angle subtended by the earth is measured by a sampling device when either of the scanning planes intersects the center of the earth. For example, the voltage proportional to θ_1 is applied to a voltage comparator which produces an output when θ_1 is equal to zero. The output voltage enables a sampler which applies a voltage β_2 to a memory unit as long as the enabling voltage is present. (β_2 is the angle subtended by the earth in the θ_2 scanning plane.) The memory unit output is used to compute altitude. Operation of the other channel is identical to that just described, so that β_1, the angle subtended by the earth in the θ_1 scanning plane, is applied to the memory unit when θ_2 is zero.

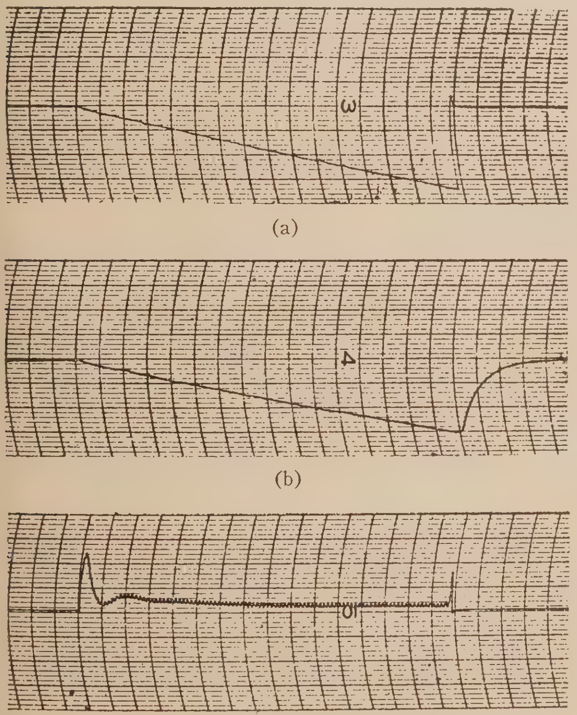


(a)

(b)

(c)

Fig. 6—Servo response to step input, ρ near 0°. Kv = 1200, paper speed = 50 mm/second unity feedback. (a) output—1 volt/mm, (b) input—1 volt/mm, (c) E_{ϵ_1} error voltage—0.2 volt/mm.

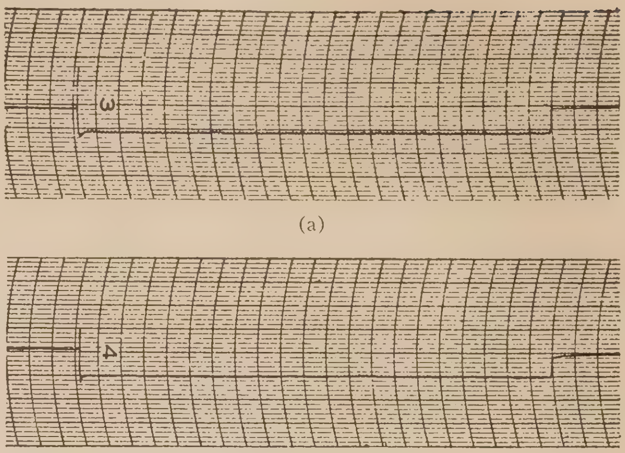


(a)

(b)

(c)

Fig. 7—Servo response to ramp input. Kv = 1200, paper speed = 50 mm/second, ramp voltage = 100 volts/second, unity feedback, (a) output—10 volts/mm, (b) input—10 volts/mm, (c) E_ϵ error—0.2 volt/mm.



(a)

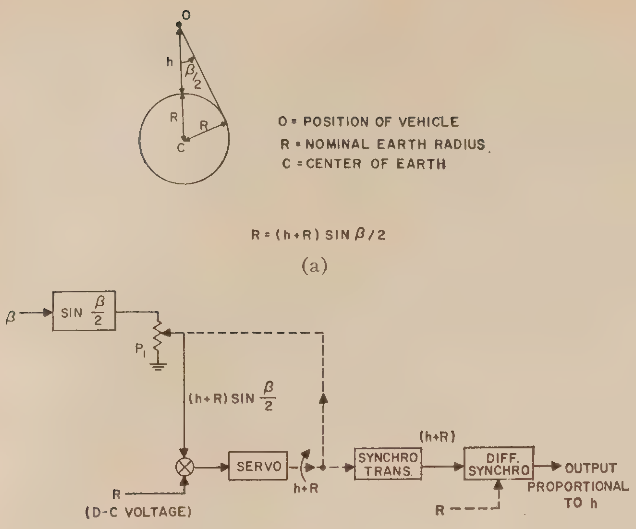
(b)

Fig. 8—Servo response to step input, ρ near 60. Kv = 4800, paper speed = 50 mm/second, unity feedback. (a) output—1 volt/mm, (b) input—1 volt/mm.

Angle β is the output of the memory device, and is used to obtain altitude by means of the circuit shown in Fig. 9(b). Derivation of the relationship between altitude (h), angle β, and nominal earth radius (R), can be found by inspection of Fig. 9(a). Sin $\beta/2$ is formed by a diode shaping network, and the product $(h+R)$ sin $\beta/2$ is derived from the output of potentiometer P_1. This product is compared with a dc voltage proportional to R, and the servo output shaft position corresponds to $(h+R)$. A differential synchro with shaft input proportional to R provides the desired output, a signal proportional to h.

Miscellaneous Sources of Error

When the scanning system intercepts direct radiation from the sun, a considerable error may result. A fixed filter is employed to reduce the effect of solar radia-but the intensity of direct radiation will far exceed that received from the earth. Probably the major trouble which will arise from direct solar radiation will be momentary disabling of the detector. The detector will not be destroyed, but it may be disabled for a period up to 1 millisecond. A means of discrimination between the solar pulse and the rise in signal when the scanner goes from space to earth could be employed, based upon pulse duration. But if the detector is disabled for 1 millisecond, the scanner will sweep blindly through 72 degrees before recovering. There does not appear to be an easy way of avoiding this trouble, but it is not as serious as it seems at first glance. The percentage of time that the sun will appear in the scanning pattern will be small if the satellite is spinning. Even if a condition should exist in which the satellite motion is such that the scanning pattern is displaced very slowly, the probability that the sun will appear in the pattern is very small.



(a)

(b)

Fig. 9—(a) Derivation of expression for altitude. (b) Possible altitude computing circuit.

Errors will arise because of irregular terrain, atmospheric layers, and cloud formations; the use of a wider beamwidth may be necessary to reduce errors resulting from these effects. In addition, the effect of satellite spin upon the position of the scanning pattern will tend to average out the errors. These things will be only partially effective, and, if it becomes necessary, a nodding mirror might be employed to sweep the scanning planes and gain further error reduction.

In order to obtain an indication of the magnitudes of errors which might arise from natural sources, calculations were made for a two-dimensional case with perfect instrumentation assumed. A profile bulge of $0.005R$ was assumed to appear on one side of the body, and the other side was assumed to be perfectly smooth. The resulting error in location of the vertical and in computed altitude is given in Table I. Distances are given in units of planet radius.

In the above calculations a very narrow beamwidth has been assumed such that no error is encountered in determining when the beam is at the edge of the planet. When a finite beamwidth is used, some error will result. This effect has been studied for a conical beam shape, with the following assumptions:

TABLE I

Altitude	Vertical Error	Altitude Error
$0.02R$	0.76°	$-0.00263R$
$0.03R$	0.61°	$-0.00262R$
$0.04R$	0.52°	$-0.00264R$
$0.05R$	0.46°	$-0.00265R$
$0.06R$	0.42°	$-0.00267R$
$0.07R$	0.38°	$-0.00269R$
$0.08R$	0.36°	$-0.00271R$
$0.09R$	0.34°	$-0.00274R$
$0.1R$	0.32°	$-0.00278R$

1) It receives no energy from sources outside the beam and has uniform sensitivity within the field of view, and
2) radiation from the earth is uniform.

It is necessary to establish the instant at which the beam center line, chosen as a reference line, is tangent to the earth. Two alternative operations on the signal were considered:

1) Differentiate the signal and let the maximum of the resulting signal denote the point of tangency, or
2) select a particular ratio of signal level to maximum signal level to represent that instant.

The first method was chosen because it appears to be more practical from the standpoint of instrumentation. Error in altitude caused by the error in determining true reference line tangency by this method is given by the expression

$$\frac{\Delta h}{h} \cong \frac{(a+1)(a+2)\alpha^2}{2-a(a+2)\alpha^2} \tag{7}$$

where

Δh = altitude error,
h = true altitude,
α = one-half of the apex angle of the beam, and
$a = h/R$, ratio of altitude to earth radius.

It should be noted that the variation of error is known as a function of altitude; hence, it is theoretically possible to compensate for it. It is doubtful, however, that such compensation will need to be used since a value as large as 0.1 for α results in errors which are small compared to those caused by terrain irregularity.

High-Speed Electrometers for Rocket and Satellite Experiments*

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Summary—**Highly stable micromicroammeters capable of measuring currents as low as 5×10^{-14} amperes with a frequency response of at least 30 cps can be realized using directly-coupled electrometer circuitry. The circuit can be packaged in approximately 9 cubic inches and requires less than 100 mw of power. An analysis of the speed of response and signal-to-noise ratio is given in the text and expressions are derived to show the theoretical possibilities of the method and to serve as design guides for realization of the maximum possible performance. Several practical circuits are shown and a summary is presented of the number of circuits which have been used in rocket and satellite exploration.**

INTRODUCTION

TRANSDUCERS such as ion chambers, photomultiplier tubes, proportional counters and ionization gauges are used to gather much of the experimental data obtained on rocket and satellite probes of space and the upper atmosphere. In the range of measurement usually encountered, the output of these devices is restricted to currents in the order of 10^{-7} to 10^{-13} amperes. Considerable amplification is then required to operate the input of a telemetering system. In general, this paper will deal with the theoretical and practical background needed to design suitable current amplifiers for this application and will describe in some detail circuits designed by the authors for the measurement of ultraviolet light and soft X-ray radiation from the sun and other celestial bodies. The circuits measure the output of a gas filled ion chamber and have a 5×10^{-12}-ampere full scale sensitivity, a frequency response of about 20 cps and a zero stability of better than 10^{-13} amperes per week.

AVAILABLE METHODS

A survey of the available types of voltage and current amplifiers will immediately narrow down the possible devices to either a dc vacuum tube electrometer amplifier or an ac amplifier used in conjunction with a capacitor modulator. The vibrating reed capacitor modulator can be immediately eliminated because of the size and power requirement of available units, the complexity of the necessary circuitry, and the difficulties inherent in modulator circuitry when speed of response is to be obtained with large feedback factors. Semiconductor devices used either directly-coupled or as modulators, or mechanical modulators do not possess either the current stability or the low noise necessary for measurement over most of the desired current range.

In keeping with the above then, it is required that the input be an electrometer vacuum tube, and specifically, because of size and performance considerations, the type CK5886, electrometer tube manufactured by Raytheon. This tube possesses the following characteristics: The input or grid current is typically less than 2×10^{-14} amperes. The input resistance is greater than 10^{14} ohms. The voltage stability with regulated plate and filament supplies is typically better than plus or minus 50 mv per week. The input current noise is typically less than 2×10^{-15} amperes peak to peak and the short circuit input noise is less than 100 μv peak to peak. The tube is a filamentary type which requires 12-mw filament power and can be operated satisfactorily with as little as 10 volts of plate supply potential.

STABILITY AND SPEED OF RESPONSE PROBLEM

The simplest method of measuring these currents with an electrometer tube is shown in Fig. 1. The tube is arranged as a voltmeter and the drop across a known value of resistance is used as a measure of the current. One difficulty then immediately becomes apparent. It has been stated above that the electrometer tube can be relied on to have a 50-mv voltage stability. It is therefore necessary that the current signal be considerably greater than this value if the device is to have negligible zero drift. Then, for example, if we desire an instrument to measure 5×10^{-12} amperes with less than 1 per cent drift per week, it is necessary to use a 10^{12}-ohm grid resistor in order that 5×10^{-12} amperes generate a 5-volt signal. Resistances of this magnitude are entirely useable and stable measurements can be made. However, the method suffers two severe limitations. First, if any amount of capacitance is present in the in-

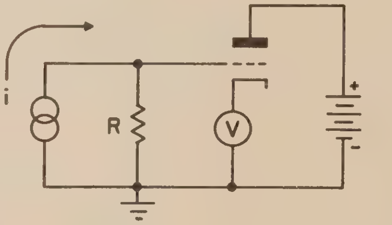

Fig. 1—Simple micromicroammeter employing voltage drop across a shunt resistor.

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* Original manuscript received by the IRE, November 23, 1959. The work reported here was performed at Keithley Instruments, Inc., Cleveland, Ohio. Parts of the work were performed under contracts to the Navy, Space Agency, and the Air Force.

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put circuitry, the response speed can be extremely slow since, for example, a 10^{12}-ohm resistor in parallel with a 10-mmf capacitor gives a 10-second time constant. This response speed would be prohibitively slow in many rocket applications. Second, a less severe limitation is that the ammeter drop is 5 volts. By the proper use of negative feedback, however, this dilemma can be resolved and fast, stable micromicroammeters can be constructed whose speed of response is relatively unaffected by input capacitance.

The method first used was first described in some detail by Pelchowitch and Zaalberg Van Zelst[1] and their article should be consulted for another equally valid analysis of the transient response problem. The basic circuit employed is shown in Fig. 2. A phase-inverting amplifier, A, is connected as shown. C_1 represents the sum of the tube input capacity and cable capacity; i_{in} is the input current; e_0 is the output voltage; C_2 is either the stray capacity or a lumped capacity placed across resistor R_1, the current-measuring resistor. Neglecting, for the moment, C_1 and C_2, to arrive at the dc response, the current i_{in} flows into the input terminal and through shunt resistor R_1. Since A is an amplifier of gain k,

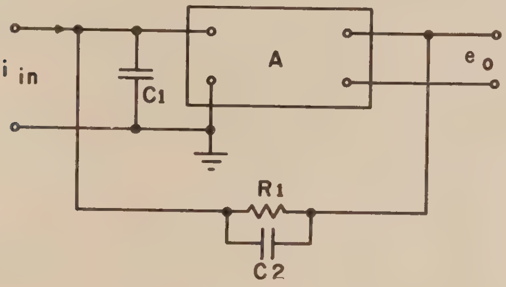

Fig. 2—Feedback micromicroammeter circuit.

$$e_{\text{in}} = e_0/k. \tag{1}$$

Since all the current i_{in} must flow through R,

$$i_{\text{in}} = -\frac{e_0}{R_1} + \frac{e_0}{R_1k}\,. \tag{2}$$

Now if k, the loop gain is large, i_{in} is simply e_0/R_1. The effective input resistance is simply $e_{\text{in}}/i_{\text{in}}$ and from (1) and (2) the effective input resistance, R_{in} is given by

$$R_{\text{in}} = \frac{R_1}{k+1}\,. \tag{3}$$

Therefore, the use of a negative feedback circuit as shown in (1) reduces input drop by a factor equal to loop gain and consequently by (3) gives the ammeter a lower effective input resistance. Also by (2), if the loop gain is large, the current sensitivity is precisely the same as if the current were being measured by means of a voltmeter and shunt resistor in Fig. 1. Then, the zero drift of the circuit will be precisely the same as in the voltmeter case provided that the circuit is being used with a current source, as is always the case in these applications.

From (3) it can be gathered that the speed of response should be increased since the effective input resistance of the ammeter is reduced. This will be shown more exactly below. In any case, however, if a substantial increase in response speed is to be obtained, the gain, k, must be large and to this end feedback factors of as much as 10^5 can be used. Various methods can be used to stabilize the loop against oscillation. One of the authors[2] has described a method to be used where it is desired to achieve stable response with R_1 at any value from zero to 10^{12} ohms. This system employs stabilizing networks internal to the amplifier to prevent oscillation. However, this method does not permit optimum performance at very low currents. The other approach is simply to let the lag formed by the input capacity C_1 and the high megohm resistor R_1 be dominant and stabilize the loop. The time constant of this lag will be sufficient in most cases to stabilize loop gains as high as 10^5. For example, with 100-$\mu\mu$f input capacitance and a 10^{12}-ohm measuring resistor this network forms a corner at 0.0016 cps. If the value of R_1 is reduced to the point where this corner is not sufficient, the loop gain may be reduced or the method discussed by Praglin[2] may be used.

ANALYSIS OF THE RESPONSE SPEED

For the purposes of circuit analysis, Fig. 2 is modified as shown in Fig. 3 to include a network in the feedback loop designated by B, the transfer function of the network. The assumption is made that k is real over the bandwidth of interest. Then the equivalent circuit is as shown in Fig. 4. The input current is given by

$$i_{\text{in}} = e_{\text{in}}pC_1 + [e_{\text{in}} - \beta e_0]\frac{1 + pC_2R_1}{R_1} \tag{4}$$

where p is the differential operator. Rearrangement of terms yields:

$$i_{\text{in}} = -e_0\left[\frac{pC_1}{k} + \frac{1 + pC_2R_1}{kR_1} + \frac{B(1 + pC_2R_1)}{R_1}\right]. \tag{5}$$

Finally, if the circuit is excited by a current square-wave, $i_{\text{in}}[U(t)]$, where $U(t)$ is the Heaviside step function and (5) multiplied by this function, the solution of the equation can easily be obtained by means of the Laplace Transformation to give

$$e_0 = \frac{-i_{\text{in}}R_1k}{1 + Bk}\left[1 - \exp\left(\frac{-t}{R_1\left[\frac{C_1}{1 + Bk} + C_2\right]}\right)\right]. \tag{6}$$

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[1] I. Pelchowitch and J. J. Zaalberg Van Zelst, "A wide-band electrometer amplifier," *Rev. Sci. Instr.*, vol. 23, pp. 73–75; February, 1952.

[2] J. Praglin, "A new high stability micromicroammeter," IRE TRANS. ON INSTRUMENTATION, vol. I-6, pp. 144–147; June, 1957.

The time constant, T, is then

$$T = R_1\left[\frac{C_1}{1 + Bk} + C_2\right] \tag{7}$$

where it is seen that the time constant formed by the input capacitance RC_1 is reduced by the feedback factor Bk. On the other hand, RC_2, the time constant formed by the resistor and any capacity across it is not affected. This fact may be used to damp the response of the amplifier by adding capacity across C_2 if desired, but in high-speed circuits this time constant must be neutralized if any speed of response is to be obtained. To this end let the network in the box labeled B in Fig. 3 have the form of the network in Fig. 5. The transfer function of this network is

$$B = \frac{1}{1 + pC_3R_2}. \tag{8}$$

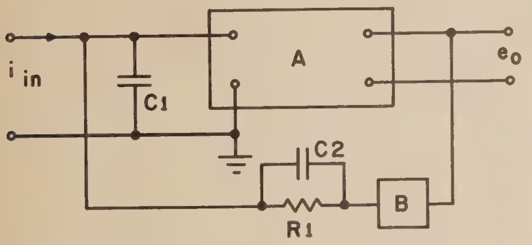


Fig. 3—Feedback micromicroammeter employing a correcting network in the feedback loop.

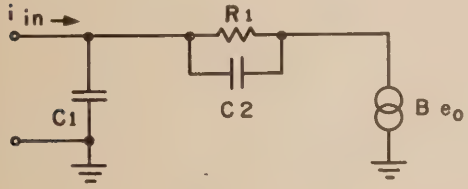


Fig. 4—Equivalent circuit of Fig. 3.

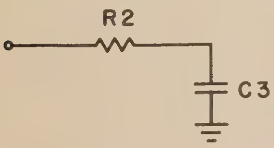


Fig. 5—Correcting network for feedback loop.

If this transfer function is substituted for B in (5) and if the condition is met that $C_3R_2 = C_2R_1$, then the third term in the parenthesis is simply $1/R_1$. Now if the Laplace Transform is used to give the network response to current step $i_{\text{in}}[U(t)]$, the result is as follows:

$$e_0 = \frac{-i_{\text{in}}R_1k}{k+1}\left[1 - \exp\left(\frac{-t}{R_1\left[\frac{C_1 + C_2}{k+1}\right]}\right)\right] \tag{9}$$

and the time constant is

$$T = \frac{R_1(C_1 + C_2)}{k + 1} \tag{10}$$

which now shows that if the above lead and lag networks are equal all time constants associated with the circuit are degenerated by loop gain.

This analysis ignores the fact that if a resistor of 10^{11} or 10^{12} ohms is suspended near a ground surface it is inevitable that stray capacity will be distributed all along the resistance element and the performance will resemble that of a delay line. It is therefore impossible to perfectly compensate the circuit so that the high megohm resistor, R_1, looks entirely resistive. In general, this consideration and the consideration of signal-to-noise ratio to be discussed presently limits the attainable speed of response. It is the usual experience that with a 10^{12} ohm resistor and very little input capacity it is possible to achieve a response of approximately 50 cps.

SIGNAL-TO-NOISE RATIO

The noise at the input of the micromicroammeter may be contributed by three sources:

1) Internal noise generators in the electrometer tube.
2) Grid current noise.
3) Johnson noise.

Internal noise generated in the electrometer tube can be represented in Fig. 6 as a voltage generator, e_n, in the cathode circuit. Grid current noise may be represented as an additional current generator, i_g, equal to $\overline{i_g{}^2(f)}_{\text{av}}{}^{1/2}$ as can the Johnson noise by a generator, i_j equal to $4ktf/R_1{}^{1/2}$. Thus the total current flowing into the input equals $i_{\text{in}} + i_j + i_g$. Neglecting e_n for the moment, this noise current is dependent on frequency exactly as is the input current. For this analysis the steady-state response to sinusoidal stimuli is sufficient, and if we again employ (5), but substitute $j\omega$ for p and (8) for B, we obtain

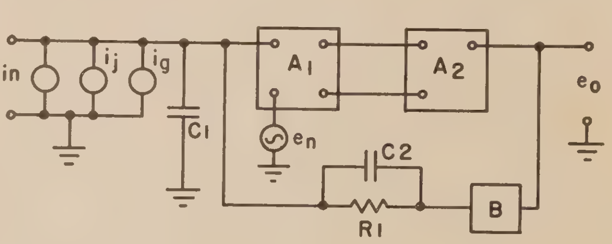


Fig. 6—Micromicroammeter with noise generators.

$$e_0 = \frac{-i_{\text{in}}R_1k}{R_1(C_1 + C_2)}\left[\frac{1}{j\omega + \dfrac{k+1}{(C_1 + C_2)R_1}}\right] \tag{11}$$

with a pole at $-[k + 1/(C_1 + C_2)R_1]$. Evaluation along the $j\omega$ axis shows that e_0 goes to zero with increasing frequency. Since i_{in} in (11) can apply to i_j, i_g, i_{in} or their sum shows that these noise sources go to zero with frequency exactly as does the signal or that at any frequency these noise sources and the input current form an unchanging ratio. Specifically, the amplitude of e_0 is given by

$$e_0 = \frac{-i_T R_1 k}{(C_1 + C_2)R_1}\left[\frac{1}{\omega^2 + \left\{\dfrac{k+1}{(C_1+C_2)R_1}\right\}^2}\right]^{1/2} \tag{12}$$

where i_T represents either the sum of i_{in}, i_j, and i_g or any one taken separately.

In general, in an electrometer circuit of this type the terms i_g and i_j are nearly negligible since the output signal is generally never less than 1 volt. The grid current of a 5886 tube is less than 2×10^{-14} amperes, measured as dc quantity, and fluctuation of this quantity about the mean dc value, which we may regard as the peak-to-peak ac grid current noise, usually does not exceed 2×10^{-15} amperes, and of course, the rms value is considerably smaller. So that, if 10^{-12} amperes of current is to be measured, the grid current noise is not more than 0.2 per cent of the signal peak-to-peak. The Johnson noise expressed as an equivalent current noise from the above expression, an assumed bandwidth of 50 cps, room temperature, and a 10^{12}-ohm resistor, amounts to about 10^{-15} amperes rms or about 5×10^{-15} amperes peak-to-peak. If smaller resistors are used, provided that the current to be measured is increased proportionally, the signal-to-noise ratio with respect to Johnson noise will be even more favorable.

The effect of internal noise sources in the electrometer tube is markedly different since this noise source is not attenuated by the circuit capacities. A brief qualitative description of the effect is helpful here. Consider the circuit of Fig. 3 with C_2 compensated for. As the frequency increases, the impedance of C_1 falls and as a result the signal obtained at the amplifier input decreases. At the same time it is the ratio

$$\frac{j\omega C_1}{R_1 + j\omega C_1}$$

which determines the feedback factor. Thus, automatically, as the signal falls at the amplifier input, the gain is increased in proportion. The result is that, as has been shown analytically, the apparent time constant of the input circuit is decreased by loop gain. Actually the physical effect of C_1 is in no way changed. We merely compensate for the attenuation caused by C_1 by boosting the forward gain of the amplifier. The difficulty with this arrangement is that the forward gain of the amplifier cannot increase beyond some practical limit since the internal noise of the first stage is constant over the entire band and is increasingly amplified as the forward gain of the amplifier increases to compensate for the capacity loading of C_1. Therefore, if the average peak-to-peak noise of an electrometer tube is 100 μv and the loop gain of the amplifier is 10^4, at some frequency the noise in the output will amount to 1 volt peak-to-peak.

A more sophisticated analysis is as follows. Let us consider the noise source e_n of Fig. 6; e_n represents the internal tube noise. Other sources of noise will be regarded as minor contributors in light of the above discussion, and their consideration will be omitted. Now from Fig. 6.

$$e_0 = k\left[e_n - \frac{e_0 B}{1 + \dfrac{j\omega C_1 R_1}{1 + j\omega C_2 R_1}}\right]. \tag{13}$$

Now if, as before, B is picked to neutralize the lead formed by R_1C_2, (13) becomes

$$e_0\left[1 + \frac{k}{1 + j\omega(C_1+C_2)R_1}\right] = ke_n \tag{14}$$

and is finally reduced to the form

$$e_0 = ke_n\left[\frac{j\omega + \dfrac{1}{(C_1+C_2)R_1}}{j\omega + \dfrac{1+k}{(C_1+C_2)R_1}}\right]. \tag{15}$$

If we are at midband, the dc signal is given by $e_0 = i_{in}R_1$, and, therefore, the signal-to-noise ratio, S, is given by

$$S = \frac{i_{in}R_1}{ke_n}\left[\frac{j\omega + \dfrac{1+k}{(C_1+C_2)R_1}}{j\omega + \dfrac{1}{(C_1+C_2)R_1}}\right], \tag{16}$$

where e_n is interpreted as the peak-to-peak noise. By the rules of complex algebra, the amplitude is given by

$$S = \frac{i_{in}R_1}{ke_n}\left[\frac{\omega^2 + \left[\dfrac{1+k}{(C_1+C_2)R_1}\right]^2}{\omega^2 + \left[\dfrac{1}{(C_1+C_2)R_1}\right]^2}\right]^{1/2}. \tag{17}$$

When ω is large, (17) reduces to

$$S = \frac{i_{in}R_1}{ke_n} \tag{18}$$

which says that the signal-to-noise ratio will eventually deteriorate to $i_{in}R_1/ke_n$. It is, therefore, of no use to make the loop gain exceed

$$k = \frac{i_{in}R_1}{S'e_n}, \tag{19}$$

where S' is the tolerable signal to noise ratio.

Eq. (17) also shows that the signal-to-noise ratio is markedly affected by the size of C_1, the input capacitance. (In most cases it will be a valid assumption to consider C_2 negligible in comparison to C_1.) If we consider the bracketed term on the right side of (17) it can be seen that if C_1 is very small,

$$\frac{1+k}{(C_1+C_2)R_1} \quad \text{and} \quad \frac{1}{(C_1+C_2)R_1}$$

are large quantities and ω must be correspondingly large before the signal-to-noise ratio deteriorates. If C_1 is a large value, it allows the ω terms to predominate at a much lower frequency. Therefore, we may conclude that the signal-to-noise ratio must deteriorate progressively with frequency; and there is a maximum loop gain which is of use as expressed by (19) for a maximum tolerable signal-to-noise ratio. Secondly, the value of C_1, the input capacitance, largely determines the signal-to-noise ratio for a specified gain and frequency band as stated in (16). Thus, since (19) specifies that the signal-to-noise ratio will reach in the limit a value dependent only on the input signal, the measuring resistor, the gain k, and the first stage tube noise, it is a waste of resources to increase the noise by increasing the loop gain beyond the k specified in (19). Now with this value of k the maximum allowable value of C_1+C_2 for a given rise time is given by (9) or by (12) for a given frequency response.

Obviously, by (17) at frequencies below those at which the bracketed term on the right is equal essentially to 1, the signal-to-noise ratio will be better and it may be argued that an improvement in signal-to-noise ratio will result with filter at the output of the amplifier to cut off the response at some lower frequency. In theory this is not true because this is in no way different from reducing loop gain. As shown by (12) the amplifier frequency response falls off on reduction of k precisely as if a low-pass filter were placed at the output. There are, nevertheless, several advantages to be gained from an output filter in practice. This is so because the input tube is usually a filamentary type tube with a pronounced mechanical resonance at about 5000 cps. Usually this frequency is far higher than the maximum operating frequency and it is of advantage to eliminate this frequency and any other sources of extraneous noise from the output.

LOGARITHMIC CIRCUITS

The resistor R_1 may be replaced by a logarithmic element such as a thermionic diode operated in a space charge limited region or a silicon diode operated on a limited portion of its forward biased region. In general, the authors have preferred the use of a 5886 electrometer tube, diode connected, as a logarithmic element, due to the wider range of measurement available (approximately 10^{-5} to 10^{-13} amperes in one range vs a range of about 10^{-4} to 10^{-10} amperes for silicon diodes), much less temperature dependence and far greater uniformity of characteristic between units than silicon offers.

Unfortunately, with logarithmic circuits, it is not possible to employ the compensation schemes used for resistive feedback. This is so since the voltage current relationship for a thermionic logarithmic current element is

$$V = A \log i_{\text{in}} + B, \tag{20}$$

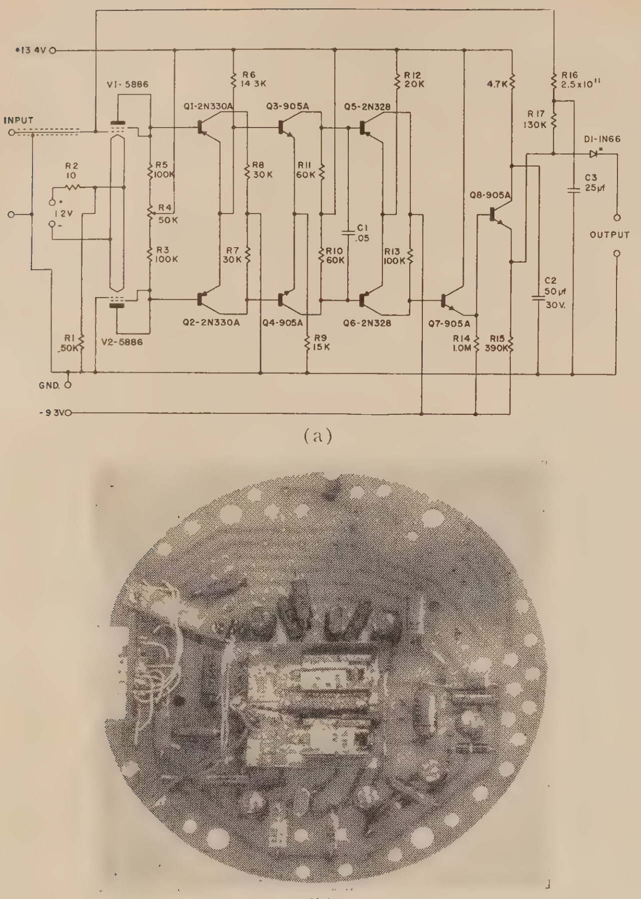
where A is the slope of the voltage current relationship and B is the residual dc voltage in the thermionic log element due to the initial emission velocity of electrons. Differentiating both sides of (20) we obtain

$$\frac{dV}{di} \equiv \frac{\Delta V}{\Delta i} = \Delta R = \frac{a}{i}, \tag{21}$$

where ΔR represents the differential resistance at some current i. Here, therefore, the feedback resistance, if the diode is used in a feedback loop, is different for different values of input current so that it is impossible to compensate for the feedback capacitance inevitably present in the diode except over a very small range. In a log circuit with a several decade range, if the circuit is critically compensated at the low-current end, the circuit will be hopelessly over-compensated at the high-current end. It is then necessary that a log circuit be overdamped at the low-current end and just achieve critical damping at the high-current end if reasonable transient response is to be achieved. Also, since the effective feedback resistance is always changing it usually is not possible to stabilize the circuit by letting the input time constant act as a dominant lag network, but additional attenuation must be supplied within the loop. If the transient response of a log circuit is considered on a small signal basis, each time sampling a different portion of the range, linear theory can apply and the method referred to by Praglin[2] can be used to analyze the results. On a practical basis, a frequency response of about 1 cps can be achieved at a current of 10^{-12} amperes, a response considerably poorer than that of a linear circuit. Logarithmic circuits, however, have proven extremely useful in many types of exploratory rocket and satellite experiments where either the range of measurement was in doubt or an extremely wide range of results were expected.

PRACTICAL CIRCUITS

The principal requirements outlined in the theoretical section require that the input circuit consist of an electrometer tube followed by sufficient gain for the desired performance. The first type of circuit used by the authors is shown in Fig. 7(a). In this circuit two electrometer tubes were employed in a balanced configuration to cancel expected changes in filament voltages. These tubes are followed by a 5-stage transistor amplifier. This circuit and modifications of it have been used in numerous NRL rocket flights and a version of this circuit is in use in the Vanguard 20-inch satellite. The maximum frequency response has been about 30 cps for a sensitivity of 5×10^{-12} amperes. For less sensitive


+13.4V
INPUT
V1-5886
V2-5886
R1 .50K
R2 10
12V
R3 100K
R4 50K
R5 100K
R6 14.3K
R7 30K
R8 30K
R9 15K
R10 60K
R11 60K
R12 20K
R13 100K
R14 1.0M
R15 390K
R16 2.5x10¹¹
R17 130K
4.7K
C1 .05
C2 50µf 30V.
C3 25µf
D1-IN66
Q1-2N330A
Q2-2N330A
Q3-905A
Q4-905A
Q5-2N328
Q6-2N328
Q7-905A
Q8-905A
OUTPUT
GND.
-9.3V

(a)

(b)

Fig. 7—Vanguard Satellite Photograph. Micromicroammeter. (a) Circuit diagram. (b) The electrometer tubes are shown in the center and are normally covered with a shield. The extra space at the top of the picture has been provided for a transistor converter power supply.

circuits the frequency response is correspondingly greater. The zero stability is in the order of about plus or minus 2 per cent of full scale per week. The power consumption of the circuit is in the order of 100 mw and the output is arranged to supply 5 volts at full scale to a telemetering system. In general, the performance has been satisfactory; however, one major difficulty has been experienced. In this configuration considerable noise contribution is obtained from the first transistor stage. This noise has the typical $1/f$ semiconductor noise distribution. This semiconductor noise is particularly annoying since it predominates at low frequencies where it is desired to make measurements. In general, tube noise except for the higher frequency mechanical resonances of the tube structure did not seem to display any noticeable $1/f$ distribution. It was possible to select germanium or silicon transistors which had satisfactory noise for the application. However, this procedure was both time consuming and annoying since a relatively small percentage of transistors, particularly silicon, would give satisfactory performance; and it was usually necessary to use silicon transistors because of the usual temperature considerations.

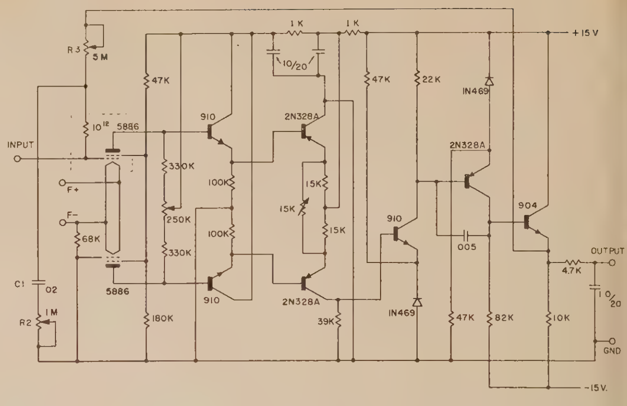

R3 5M
10¹² 5886
INPUT
F+
F-
68K
5886
C1 .02
R2 1M
47K
330K
250K
330K
180K
910
100K
100K
910
1K
1K
10/20
2N328A
15K
15K
15K
2N328A
39K
47K
22K
910
IN469
IN469
2N328A
005
47K
82K
904
10K
+15V
OUTPUT
4.7K
10/20
GND
-15V.

Fig. 8—Circuit schematic diagram of improved balanced input electrometer tube and transistor circuit.

An alternate circuit which offered some improvement over the first circuit is shown in Fig. 8. Balanced electrometer tubes are still used but the electrometer tubes are followed by emitter-follower stages. With silicon transistors it is possible to achieve about a 1-meghohm plate circuit impedance and if the 5886 tubes are then connected as pentodes it is possible to obtain a voltage gain of about 10. In the previous circuit the voltage gain from the grid to plate of the electrometer tubes is less than 1.0. This arrangement, as might be expected, offers a 10:1 reduction in transistor noise over the first circuit through a better impedance match between the electrometer tubes and the transistor stages. With this circuit, transistor selection is not as critical although some selection is still necessary. As far as other performance specifications and power consumption, it is essentially the same as the first circuit.

The requirements of low power consumption had, at the beginning of the project, seemed to dictate the use of transistors wherever possible. Use of a balanced input stage had been made necessary by the possibility of shifting battery voltages. However, due to the difficulties experienced with semiconductors, the possibility that a tube amplifier would give better results seemed worth considering. Also the requirements for operation from batteries had changed to operation with transistor inverter supplies. With these supplies it is not much more difficult to provide very close regulation of output voltages with zener diodes and transistorized feedback regulators. The circuit in Fig. 9(a) shows the new approach. Four subminiature tubes are used in the main amplifier and two transistors in the output stage. The power requirement for the series filament string is only 3 volts at 10 ma or 30 mw. Since it is possible to run subminiature tubes at far lower plate currents with adequate gain than it is possible to operate transistor collector circuits, the total plate current requirement is 40 μa at 20 volts or 0.8 mw. The output transistor stages dissipate about 8 mw at no signal. The total power requirement is then less than 40 mw against perhaps 100 mw for the previous circuit. The circuit is

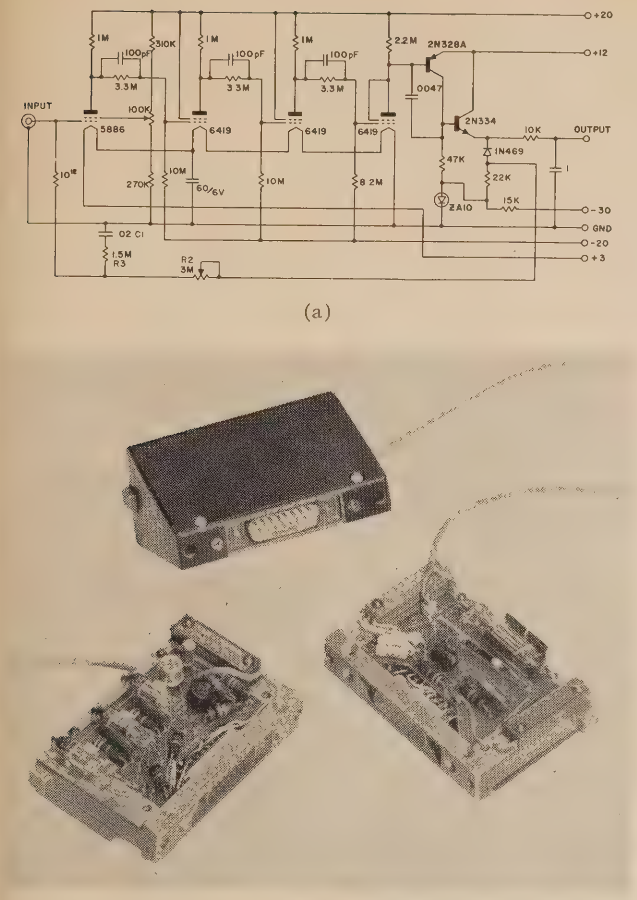

+20
+12
1M
310K
1M
1M
2.2M
2N328A
100pF
100pF
100pF
3.3M
3.3M
3.3M
.0047
INPUT
100K
5886
6419
6419
6419
2N334
10K
OUTPUT
1N469
47K
22K
15K
10^{12}
270K
10M
60/6V
10M
8.2M
2A10
-30
GND
-20
+3
.02 C1
1.5M
R3
R2
3M
(a)
(b)

Fig. 9—(a) Circuit schematic diagram of subminiature tube circuit employing transistors only in the output circuit. (b) Photograph of the circuit of (a). The dimensions are $2\times3\times1\frac{1}{2}$ for the largest part of the wedge cross section. At the top is the complete unit with the case. Below, at the left, the side carrying the three 6419 tubes and the output transistors is shown. At the right the input stage with the electrometer tube and the high megohm resistor is seen.

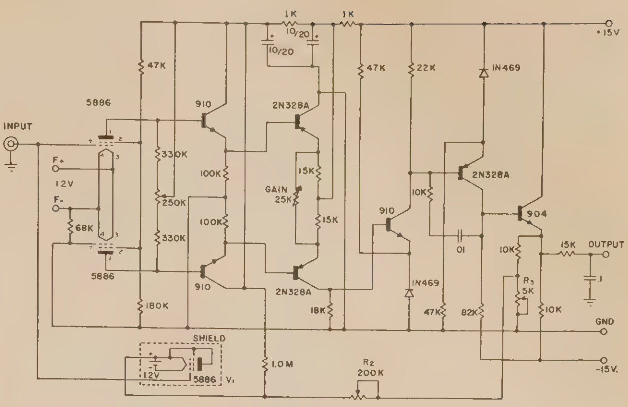

1K
1K
10/20
10/20
+15V
47K
47K
22K
1N469
5886
910
2N328A
INPUT
F+
12V
F-
330K
100K
15K
GAIN 25K
2N328A
10K
250K
100K
15K
910
904
68K
330K
.01
10K
15K
OUTPUT
.1
5886
910
2N328A
1N469
R3 5K
180K
18K
47K
82K
10K
GND
SHIELD
12V
5886 V1
1.0M
R2 200K
-15V.

Fig. 10—Circuit schematic diagram of a logarithmic micromicroammeter using type 5886 tube connected as a diode.

characterized by a signal-to-noise ratio with no component selection which is consistently at least as good as the best performance of the previous two circuits with selected transistors.

In all three circuits a network, which has been referred to (Fig. 3) in the Theoretical Section, has been employed to compensate the response. In early circuits, the exact form of compensation circuit referred to in the article was used, and fixed value components were soldered in. However, in the circuits of Figs. 8 and 9 the compensation network is adjustable by means of carbon potentiometers for greater convenience. It was also found that, in practice, the trimming of the circuit was facilitated by adding an additional resistance in series with the capacitor of the compensating network and also making this additional resistance variable. (See R_3, C_1, and R_2 of Figs. 8 and 9). This additional resistance helps to compensate for excess phase shift introduced by the distributed nature of the stray capacitance to the high meghohm resistor body and the phase shift introduced in some cases by the amplifier. Figs. 7(b) and 9(b) are photographs of two of the circuits.

In Fig. 10 is shown a logarithmic circuit. The general approach is similar to the linear circuits except for the log diode. The power supply for the logarithmic element, V_1, is floating and potentiometer R_2 taps off a voltage to buck-out the initial emission voltage of the diode. This particular circuit has a range of 10^{-5} to 10^{-11} amperes without scale changing. Potentiometer R_3 determines the forward gain of the amplifier and hence the slope of the log voltage current relationship. This circuit has a frequency response of about 7 cps at 10^{-11} and several thousand cps at 10^{-5} amperes. The stability after a short warmup is better than 5 per cent of a decade per day.

METHODS OF TESTING TRANSIENT RESPONSE

It is extremely difficult, by ordinary methods, to generate current step functions or sinusoidal waves of known amplitude in the region of 10^{-8} to 10^{-12} amperes. The use of a resistor with a known potential is useless except at dc because of the stray capacities involved. In the course of this investigation two methods have been found satisfactory.

1) The generation of current wave forms by the modulation of light input to a photocell.

2) The use of a triangular wave generator with a small capacitance to generate a current step function.

The first method is free of any theoreitcal objections and lends itself, with a little ingenuity, to the generation of both sine and step functions of current. The main drawback is that it is difficult to find phototubes with a low enough dark current to make the measurement conveniently and that the apparatus involved is somewhat clumsy.

The second method is outlined in Fig. 11. The triangular wave may be obtained with a commercial triangular wave generator and the current output is a square wave the rise time of which is dependent on the *RC* product of the network. By routine circuit analysis the rise time and amplitude of the current step is

$$i_0 = aC(1 - e^{-t/RC}) \tag{22}$$

where a is the slope of one segment of the triangular wave. Thus, if C or R is small enough, a satisfactory current square wave may be generated. The method becomes more interesting in view of (3) which stated that in the feedback circuit the input resistance is further reduced by loop gain. Thus, for example, if we assume that (22) may be applied to the feedback circuit of Fig. 2, with (3) giving the actual input resistance, we may make the following sample calculation. Let us assume that k equals 1000, R_1 is 10^{12} ohms (Fig. 2) and C (Fig. 11) is 1 $\mu\mu$f. Now by (3) the R_{in} of Fig. 11 is 10^9 ohms so that by (22) the time constant of the step function rise is 1 msec; and if a equals 1 volt per second the dc value of the current (equal to ac) is 10^{-12} amperes. This rise time at 10^{-12} amperes would be more than satisfactory.

For an exact analysis refer to Fig. 12. This is the same as Fig. 1 except C_3, the current injecting capacitor, is added. Fig. 13 gives the equivalent circuit which leads to the following equations:

$$e_{\text{in}} = i_1\left(\frac{1}{pC_3} + \frac{1}{pC_1}\right) - i_2\frac{1}{pC_1}$$

$$-e_0 = -i_1\left(\frac{1}{pC_1}\right) + i_2\left(\frac{1}{pC_1} + \frac{R_1}{1 + pC_2R_1}\right). \tag{23}$$

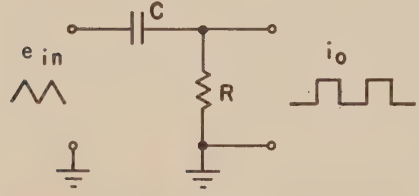


Fig. 11—Triangular wave method of generating a current square wave.

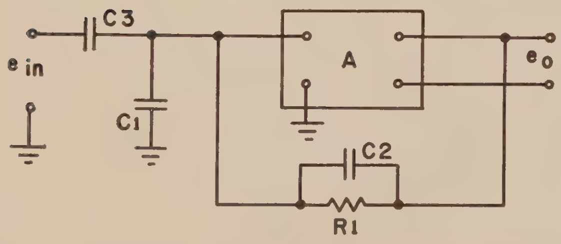


Fig. 12—Micromicroammeter with current injecting capacitor C_3.

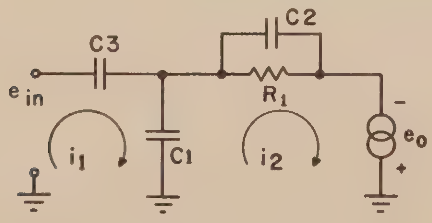


Fig. 13—Equivalent circuit of Fig. 12.

Solution of these equations and stimulation of the network by $e_{\text{in}} = at$, where a is the slope of the ramp function and t is the time, yields, by the Laplace transform method, the result

$$e_0 = \frac{-aR_1C_3k}{k+1} \cdot \left[1 - e^{\left(\frac{-t}{R_1\left[\frac{C_3}{k+1} + \frac{C_1}{k+1} + C_2\right]}\right)}\right] \tag{24}$$

and the time constant is

$$T = R_1\left[\frac{C_3}{k+1} + \frac{C_1}{k+1} + C_2\right]. \tag{25}$$

Therefore, if C_3 the current injecting capacitor is not larger than C_2, even if k were 1, the error would be no more than 50 per cent. If C_1 is much larger than C_2 or C_3, even with $k=1$, the error in rise time caused by the presence of C_3 will be entirely negligible. With even a moderate loop gain, a fairly large value of C_3 causes no error, and the time constant measured is essentially that of the normal circuit capacities C_1 and C_2. In practice, therefore, to be sure of no error, C_3 should just be large enough to couple into the circuit sufficient step height for convenient measurement (i_{in} equal to aR_1C_3). At very low currents stray circuit capacity will suffice for coupling the signal.

It should be pointed out that the validity of current testing method must be established beyond question before any specification of transient response may be trusted.

APPLICATION

In 1958 and 1959 the U. S. Naval Research Laboratory employed some fifty of these electrometer amplifiers in the upper air research program. A brief summary of flights already accomplished is given in Table I.

In general, the detectors produce a dc current when exposed to radiation in a selected portion of the X-ray or ultraviolet light spectrum. Thus, as the vehicle spins about its axis, the output of the detector varies in a manner determined by the viewing angle of the detector, the spin rate of the vehicle, and the nature of the body producing the radiation. Typical vehicle spin rates have been 1 to 10 rps. In many cases the detector viewing angle has been quite broad allowing the use of circuits with 20 to 50 cps bandwidth. On several occasions, however, narrow collimation has been dictated by the nature of the experiment. One such case was a proportional counter experiment which required an amplifier with a bandwidth of 300 cps and a full scale sensitivity of 10^{-10} amperes.

Circuit performance in flight has, in general, been satisfactory. On two occasions in Aspan flights a noticeable deterioration in frequency response was observed beginning at about 120 seconds of flight and continuing to impact. The apparent cause of this deterioration was

TABLE I
Summary of Rocket and Satellite Flights Using Electrometer Circuits

Vehicle Type	Detectors	Electrometer f.s. Sensitivity	Number of Electrometer Circuits
Vanguard Eta	ion chamber	2×10^{-11} A	1
Explorer VII	ion chamber	2×10^{-11} A	1
Aerobee	ion chamber	2×10^{-11} A	3
	ion chamber	5×10^{-12} A	5
Aspan	ion chambers, photomultipliers, proportional counters	2×10^{-11} A	4
		1×10^{-7} A	4
		6×10^{-12} A	19
		1×10^{-10} A	4
		1×10^{-11} A	1
		5×10^{-10} A	1
		5×10^{-11} A	5

transistor changes resulting from excessive temperature rise of the package. In these flights germanium transistors had been used.

Some interference from RF fields has geen encountered in complete flight instrument packages. Usually this type of interference has been eliminated by using ceramic bypass capacitors on each lead entering the electrometer amplifier except for the signal input lead which is shielded.

Acknowledgment

The authors would like to express their appreciation for the assistance furnished by the following in various phases of this work: D. Brousseau of NRL, Dr. J. Lindsay, Dr. J. E. Kupperian of NASA, W. Krawczonek, and T. Dambach of Keithley Instruments.

The Hydrogen Quartector®—A New Phase Detector for Exotic Liquid-Gas Systems*

R. L. BLANCHARD†, SENIOR MEMBER, IRE, AND A. E. SHERBURNE†, MEMBER, IRE

***Summary*—The problem of an instrument to discriminate automatically between liquid and gaseous hydrogen has been solved. The principle of operation involves the dependence of acoustic radiation resistance upon density of the medium. The instrument comprises a quartz piezoelectric vibrator immersed in the medium and developing at its terminals a radiation resistance, and an electronic unit external to the medium, which automatically converts this resistance to a signal for measurement or control. The system is suitable for use with most fluids, including hydrogen, oxygen, and kerosene. Hydrogen is of particular interest because low density provides a less distinct interface, particularly at high pressure.**

The radiation resistance of practicable sensor configurations is analyzed for a number of fluids and experimental data are presented for conditions of liquid, gas, and wet in gas. An electronic technique for precise conversion of radiation resistance to a control signal is described. A stable negative resistance is generated, and maintenance of oscillation is the criterion for radiation resistance greater or less than the prescribed value of negative resistance. This negative resistance is chosen to be intermediate in value between the values which obtain for liquid and gas phases. Stable radiation resistance resolution of a few per cent has been obtained easily without encountering any limiting condition.

An example of equipment designed for missile environmental conditions is described.

List of Symbols (MKS Units)

Electrical

C = capacitance
E = potential
L = inductance
L_c = intrinsic crystal inductance
L_r = inductance caused by acoustic radiation
Pav = average power, watts
Q = ratio of reactance to resistance
R = net resistance
R_c = intrinsic resistance of mounted crystal
R_n = negative resistance absolute value
R_p = positive resistance
R_r = resistance caused by acoustic radiation
ω = frequency radians per second
X = reactance
Z = impedance.

Piezoelectric

d_{11} = piezoelectric strain coefficient, 2.3×10^{-12} meters/volt
s_{11} = compliance coefficient, 1.27×10^{-11} meters/newton

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* Original manuscript received by the IRE, November 23, 1959.
† New Products Research, Trans-Sonics, Inc., Burlington, Mass.

l_x = crystal dimension along x axis
l_y = crystal dimension along y axis
l_z = crystal dimension along z axis.

Acoustic

c = velocity of propagation
D = piston diameter
J_1 = Bessel function
K_1 = Bessel function
Pav = average power, joules/second = watts
R_a = acoustic resistance
S = piston area
v = velocity
x = dimensionless parameter
X_a = acoustic reactance
Z_a = acoustic impedance, ratio of force to velocity
ρ = density of the medium
ξ = normalized acoustic resistance
η = normalized acoustic reactance.

I. INTRODUCTION

In the control of fuel for liquid-propelled missiles and rockets, need has arisen for a switch to discriminate automatically and reliably between liquid and gas phases. Kerosene, liquid oxygen, and liquid hydrogen flowing in pipes or contained in tanks, and operation on the ground or in flight, typify the environmental conditions.

II. PRINCIPLE OF OPERATION

The phenomenon on which the system is based is the acoustic radiation resistance of a small piezoelectric vibrator immersed in the medium. This resistance is a function of ρ and c, both of which are different in liquid and gas phases. The functional dependence is determined by the design of the sensor, as will be brought out in Section III, and the sensor can be designed for large discrimination over wide operating conditions. The radiation resistance is a mechanical resistance developed at the "piston" surfaces of the vibrator and is converted by the piezoelectric phenomenon into a corresponding electrical resistance. At the terminals of the piezoelectric crystal, an electrical impedance is observed which is a combination of the equivalent acoustic radiation resistance and reactance, the equivalent electrical resistance of the crystal due to internal losses, the equivalent electrical inductance and capacitance corresponding to the mass and elasticity of the crystal, and the electrical capacitance between the electrodes. All of these elements of the sensor impedance are shown in Fig. 1. Of these, the radiation resistance is a strong function of the properties of the medium in which the sensor is immersed. The remaining part of the system comprises a mechanism for automatically sensing the value of this resistance.

The technique for sensing radiation resistance R_r comprises the generation of the negative admittance shown in Fig. 2, where C_n and R_n represent the absolute magnitudes of a negative capacitance and negative resistance respectively. For the condition $C_n \cong C_e$, the parallel connection of Figs. 1 and 2 is represented by the circuit of Fig. 3. Oscillations are sustained in this circuit in accordance with the criteria:

$$R_p = R_c + R_r$$

$$\text{oscillate } R_n > R_p$$

$$\text{not oscillate } R_n < R_p.$$

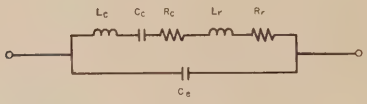

Fig. 1.

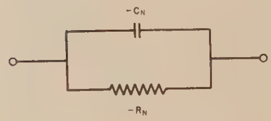

Fig. 2.

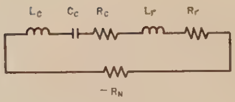

Fig. 3.

Since R_c may be designed to be much smaller than R_r, R_n is a very sensitive criterion for the magnitudes of R_r. If R_n is chosen to be intermediate between the values of R_r for liquid and gas phases of some medium, oscillations are sustained in the gas phase but not in the liquid phase. In the circuit of Fig. 3, the impedance across any element may be described mathematically as a simple pole in the complex plane lying in the left half plane when the sensor is in liquid and in the right half plane when the sensor is in gas.

The presence or absence of oscillation in the circuit is easily converted into a corresponding open or closed position of a relay or transistor switch for indication or control.

Speed of Response

The parameters in Fig. 3 determine the rate of growth or decay of oscillations. For small amplitudes of oscillation R_n is constant, and the relay circuit is designed to operate in this region. At some higher amplitude, R_n diminishes with increasing amplitude, and a stable equilibrium is achieved. In the region of linear operation the oscillations are described as follows:

$$a = a_0 e^{\sigma t} \sin wt = A_{(t)} \sin wt \tag{1}$$

$$\sigma = -R/2L = -w/2Q \tag{2}$$

$$R = R_r + R_c - R_n \tag{3}$$

$$L = L_c + L_r. \tag{4}$$

The time interval for growth or decay of oscillations is described as follows:

$$A_{(t2)}/A_{(t1)} = K = e^{\sigma(t_2-t_1)} = e^{\sigma\Delta t} \tag{5}$$

$$\Delta t = \frac{1}{\sigma}\log_e K. \tag{6}$$

Log K and σ are positive for increasing oscillations (gas), and negative for decreasing oscillations (liquid). To determine the switching time, the values are inserted in (5) for $A_{(t2)}$ and $A_{(t1)}$ equal respectively to the relay closure value and the random noise voltage in the absence of oscillations. An oscillogram showing the rapid growth and decay of oscillations for circuit parameters representing the case of hydrogen, liquid and gas, at atmospheric pressure is shown in Fig. 4. A representative time interval for growth of oscillations for this case is somewhat less than 100 msec and for oxygen somewhat less than 10 msec. The corresponding times for decay of oscillation are smaller.

Thus the response time is dependent upon the medium in an interesting way. The value of R in (2) and (3) is the difference between R_n and R_p. If R_n is chosen intermediate between the values of R_p for liquid and gas, then R is one half the difference between the resistance in liquid and the resistance in gas. The smaller the difference between liquid and gas resistances, the longer the time of response for a given sensor design. By making R in (3) very small, the time Δt in (6) can be arbitrarily long. In order to illustrate the growth and decay of oscillations, the following experiment was performed. A sensor with resistance R_p between 1000 and 1100 ohms and with inductance $L \cong 36h$ was connected to negative resistance R_n chosen to have values in sequence $R_{n1} = 1100$ and $R_{n2} = 1000$ ohms.

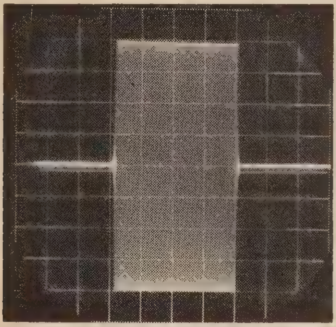

Fig. 4—Speed of response hydrogen switching condition.

Thus

$$|R_{n1} - R_p| + |R_p - R_{n2}| = 100.$$

The circuit Q, therefore, was approximately 500,000. The oscillogram in Fig. 5 where the sweep rate was one vertical line per second shows the corresponding growth and decay of oscillations. Values of K and Δt determined from the oscillogram and (2) and (6) yield the following magnitudes:

$$|R_{n1} - R_p| \cong 39\Omega$$

and

$$|R_p - R_{n2}| \cong 52\Omega.$$

The sum of these (91 ohms) approximates the experimental value, allowing for the approximate value for L.

III. Acoustic Radiation and Electrical Resistance

The vibration of a piezoelectric sensing element radiates sound energy into the surrounding medium. This energy is supplied by the alternating electric field appearing across the crystal. The medium tends to restrain the crystal vibrations, thus requiring a greater voltage to achieve the same extensional amplitude compared to the unloaded crystal. If the crystal extension is maintained constant while the restraining force is varied, then it is clear that the acoustic power radiated is proportional to the force. For a given crystal, the voltage required to produce a given extension is proportional to the force required. Since the electrical power must equal the radiated power, the electrical resistance of the crystal must be proportional to the restraining force.

The reaction of a medium on the vibrating crystal depends on the density of the medium, the velocity of sound in the medium, and the dimensions of the crystal. The loading effect is similar to the acoustic loading on a vibrating piston. The solution for a cylindrical piston in an infinite baffle is well known:

$$Z_a = \rho c S[\xi + j\eta] = R_a + jX_a \tag{7}$$

where

$$\xi = 1 - \frac{2J_1(x)}{x} = \frac{x^2}{2\cdot 4} - \frac{x^4}{2\cdot 4^2\cdot 6} + \frac{x^6}{2\cdot 4^2\cdot 6^2\cdot 8} - \cdots \tag{8}$$

$$\eta = \frac{2K_1(x)}{x^2} = \frac{4}{\pi}\left(\frac{x}{3} - \frac{x^3}{3^2\cdot 5} + \frac{x^5}{3^2\cdot 5^2\cdot 7} - \cdots\right). \tag{9}$$

In this paper we are primarily interested in R_a, since this appears as a resistance in the electrical equivalent circuit. Although X_a appears in the equivalent circuit as a reactance, it serves only to cause a slight frequency shift in the oscillator.

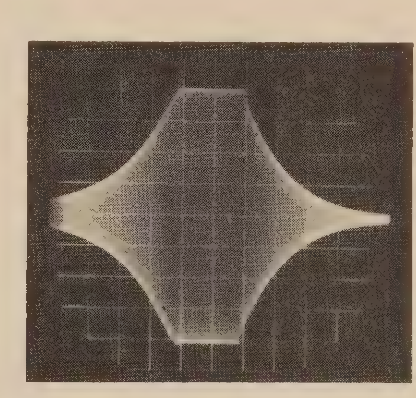

Fig. 5—Growth and decay of oscillations.

In (7), ρc is the characteristic impedance of the medium per unit area, S the area, and the term in brackets characterizes the size and shape of the piston in terms of a wavelength in the medium. For a circular piston, $x = wD/c$. For the rectangular piston used in the design described in this paper, we have used the dimension 1.7 l_x in place of D where l_x is the smaller of the two piston dimensions, giving:

$$x = \frac{1.7 w l_x}{c}\cdot \tag{10}$$

This estimated value for x has been used in lieu of performing a pressure integration over the piston face, and for the requirements of the application has been quite adequate.

It is interesting to observe the effect of sensor dimensions on the functional dependence of R_a upon ρ and c. For x large, *i.e.*, for a piston in which the smallest dimension is larger than a wavelength in the medium, R_a is roughly proportional to ρc. For x small, R_a is roughly proportional to ρ/c as the following development shows: For $x<1$, it is convenient to use the power series form for Z_a:

$$R_a = \rho c S\left[\frac{\left(\frac{2\pi f D}{c}\right)^2}{2\cdot 4} - \frac{\left(\frac{2\pi f D}{c}\right)^4}{2\cdot 4^2\cdot 6} + \cdots\right]$$

$$\cong \frac{(2\pi)^2 D^2 f^2}{8}\,\frac{\rho}{c}\,S \quad \left(\frac{2\pi f D}{c} < 1\right) \tag{11}$$

and

$$X_a = \frac{4}{\pi}\,\rho c S\left[\frac{\left(\frac{2\pi f D}{c}\right)}{3} - \frac{\left(\frac{2\pi f D}{c}\right)^3}{3^2\cdot 5} + \cdots\right]$$

$$\cong \frac{8 D f \rho}{3}\,S \quad \left(\frac{2\pi f D}{c} < 1\right) \tag{12}$$

where f is the frequency of the radiated energy.

The preceding equations describe a mechanical impedance at the piston surface. The corresponding electrical impedance which is developed in the sensor equivalent circuit (Fig. 1) can be obtained by the following argument.

The acoustic power radiated is:

$$\text{Pav} = \tfrac{1}{2} R_a V_0^2 \tag{13}$$

where the piston velocity is:

$$v = V_0 \cos wt. \tag{14}$$

The electrical power supplied to the crystal is:

$$\text{Pav} = \frac{E^2}{2R_r} \tag{15}$$

where R_r is the electrical resistance corresponding to the acoustic radiation resistance R_a and E is the peak applied voltage. Setting the two expressions equal and solving for R_r:

$$R_r = \frac{E^2}{V_0^2 R_a}\cdot \tag{16}$$

The velocity of the end of a crystal driven by a sinusoidal voltage $E \cos wt$ is:

$$v = \frac{d_{11} S}{s_{11} l_x R_a}\, E \cos wt. \tag{17}$$

Therefore

$$V_0 = \frac{d_{11} S E}{s_{11} l_x R_a}\cdot \tag{18}$$

Solving for E/V_0 and substituting in the expression for R_r yields

$$R_r = \frac{s_{11}^2 l_x^2}{d_{11}^2 S^2}\, R_a \tag{19}$$

$$R_r = \frac{s_{11}^2}{d_{11}^2}\,\frac{l_x}{l_z}\,\rho c\left(1 - \frac{2J_1(x)}{x}\right)\cdot \tag{20}$$

Eqs. (10) and (20) have been used in subsequent computations.

For $x<1$, the approximate expression for R_r corresponding to (20) becomes:

$$R_r \cong (2\pi)^2\,\frac{s_{11}^2}{d_{11}^2}\cdot\frac{(1.7)^2 f^2 l_x^3}{8 l_z}\,\frac{\rho}{c}\cdot \tag{21}$$

The resistance for both crystal faces is one half this value

IV. Impedances of the Sensor in Liquids and Gases

The impedance of the sensor has been computed and measured for a variety of gases and liquids. Measurements of the impedance magnitude in liquids was performed with a transmission circuit which uses the sensor in a voltage-dividing network. The sensor impedance magnitude is thus compared to a known resistance. Resistance measurements have been made by an alternate technique for the case of liquid hydrogen and for several gases. In this experiment, the values for R_n for which oscillations grow and decay are measured. These data are in agreement with the transmission circuit data.

Table I gives computed radiation resistance values in electrical ohms for several liquids and gases. Eq. (20) was used for all calculations, with D taken as 0.070 inch. Data for density and velocity of sound were taken from several sources for which references are given at the end of Table I. These data are in conformance with the experimental data now to be described within the accuracy to which calculations and measurements were attempted.

The impedance magnitude of the sensor in liquid nitrogen experimentally is shown in Fig. 6. The curve is

TABLE I

Calculated Radiation Resistances of Gases and Liquids

Gas	Temperature, °K	Pressure, atmospheres	Radiation Resistance, ohms
Argon[1]			
	300	1	800
	300	10	8,100
	300	40	33,000
	300	70	59,000
	300	100	84,000
Helium[2]			
	255	1	50
	255	100	4,900
Nitrogen[1]			
	100	1	1,300
	200	1	830
	300	1	550
	300	10	5,600
	300	100	53,000
Oxygen[1]			
	120	1	1,300
	300	1	650
	300	10	7,000
	300	100	59,000
Liquids			
Hydrogen[3]	20	1	15,000
Nitrogen[3]	77	1	220,000
Oxygen[3]	90	1	310,000
JP-4[2]	298	1	160,000
UDMH[4]	298	1	160,000

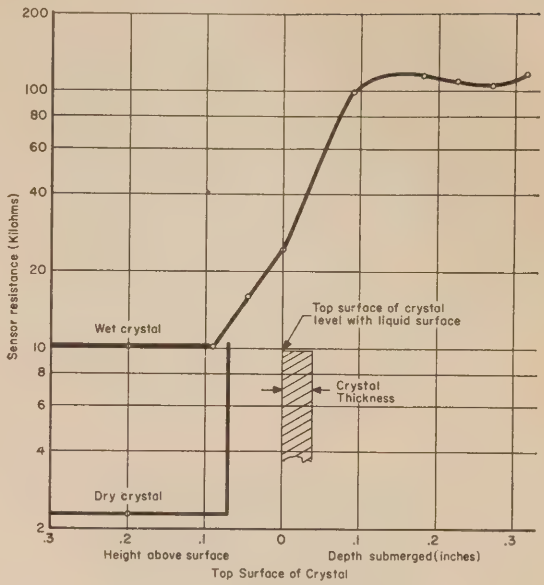

Fig. 6—Sensor impedance magnitude in liquid N_2 atmospheric pressure.

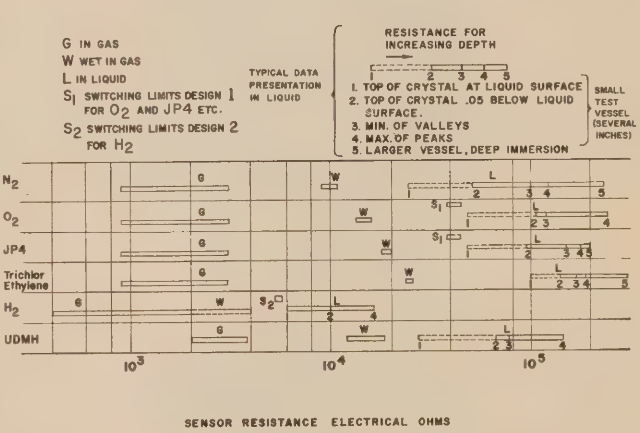

Fig. 7—Sensor impedance magnitude in liquids.

plotted starting with a dry sensor and slowly lowering it into the liquid. The impedance jumps suddenly when the crystal is still about $\frac{1}{16}$ inch above the liquid because surface tension causes some liquid to flow up the support wires and wet the crystal. The impedance rises rapidly until the crystal is submerged about $\frac{1}{10}$ inch below the surface. A slight oscillation in the impedance with increasing depth is caused by reflections from the surface. This effect disappears as the sensor depth is increased slightly. When the sensor is removed, some of the liquid adheres and the sensor resistance is considerably higher than that of the dry sensor. Evaporation of the liquid finally returns the impedance to its original value. The curve of Fig. 6 is typical of curves obtained for all liquids except that the wet and submerged values, of course, are different for different liquids. Fig. 7 shows the range or impedances measured for several liquids. The wet impedances as well as the submerged impedances are shown. The bars marked S_1 and S_2 represent the performance of two switches, one designed for liquid oxygen and the other for liquid hydrogen. The extremities of each bar show the range of impedance values for which switching is assured for interchangeable units over military environmental conditions. Notice that, in both cases, the switching limits are well removed from the extreme values measured for 0.05-inch submersion on one side and for a wet crystal in gas on the other.

Experimental data for the impedance of the sensor in gases are given in Fig. 8. The rising characteristic of the curves for helium and nitrogen is believed to be caused by a reflection of acoustic waves from the glass header of the sensor and the variation in the velocity of sound with pressure. Note that the resistance which is plotted is the sum R_c+R_r. For the sensor used in these measurements, R_c was approximately 800 ohms. These data were obtained from transmission measurements and verified by the measurement of the negative resistance required to cause oscillations.

V. Electronic Discrimination of Impedance

Automatic classification of sensor impedances as greater or less than a prescribed value is accomplished by two functions:

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[1] J. Hilsenrath, C. W. Beckett, W. S. Benedict, L. Fano, H. J. Hoge, J. F. Masi, R. L. Nuttall, Y. S. Touloukian, and H. W. Woolley, "Tables of the Thermal Properties of Gases," NBS Circular 564; November, 1955.

[2] Anonymous, "Liquid Propellants Handbook" (Confidential), 3 vols., Battelle Memorial Inst., Columbus, Ohio, Contract No. (AS) 54-597C with the U. S. Dept. of the Navy; October, 1955.

[3] R. B. Scott, "Cryogenic Engineering," D. Van Nostrand Co., Inc., Princeton, N. J.; 1959.

[4] Anonymous, "Storage and Handling of Dimazine (unsym-Dimethylhydrazine)," prepared by Res. and Dev. Dept. of Westvaco Chlor-Alkali Div., Food Machinery and Chemical Corp., New York, N. Y., 3rd ed.

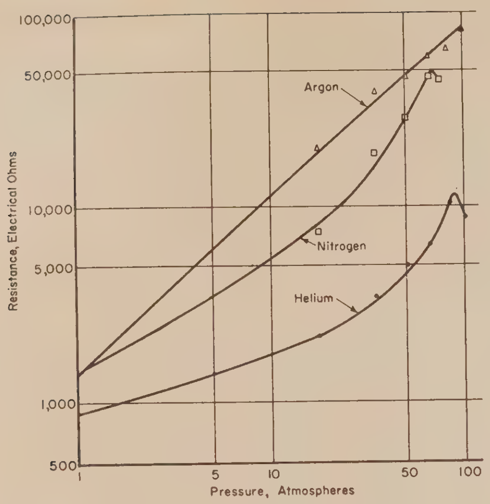

Fig. 8—Sensor resistance vs pressure for several gases at approximately 70°F.

1) generation of a negative admittance of prescribed value; and
2) detection of oscillation and operation of a control circuit (relay or transistor switch).

Fig. 9 illustrates the generation of negative admittance. It comprises an amplifier with gain A over a bandwidth large compared to the bandwidth of the circuit in Fig. 3. This network generates the negative admittance indicated in Fig. 2 in accordance with (22)–(24).

$$\frac{1}{Y_n} = -\frac{Z_f}{1 + \left(\frac{Z_f + 2R_1}{AR_1}\right)}\left[1 - \frac{1}{A}\left(2 + \frac{3R_1}{Z_f}\right)\right] \tag{22}$$

$$C_n \cong C_f \tag{23}$$

$$R_n \cong R_f\left[\frac{1}{1 + \frac{R_f}{AR_1}}\right]. \tag{24}$$

For a large and stable value of AR_1, stable values of R_n are obtained over a wide range of values by choice of R_f. An illustration of this is given in Fig. 10 where (24) for R_n vs R_f is plotted. Also shown in the lower part of the illustration is the result of an experiment where for a given value of R_f, the values of a positive resistance R_p, for which the circuit does or does not oscillate and operate a control circuit, are plotted. This is indicated for eight values of R_f, and the differences between these values and the computed value of R_n are shown. In the experimental equipment in which these data were contained, R_p was known only to an accuracy of about one per cent, and the smallest step which could be made in R_p was 10 ohms. Thus, the placement of the bars on the page include about a one per cent uncertainty due to experimental equipment.

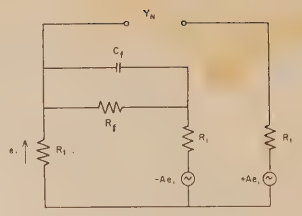

Fig. 9.

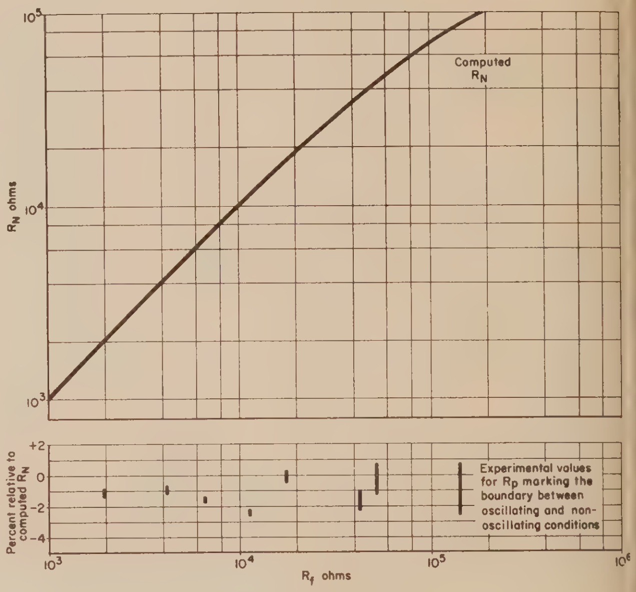

Fig. 10—Electronic unit resistance resolution.

Although electronically generated, a high degree of stability and predictability is achieved in the negative resistance R_n. In (25), the dependence of R_n upon R_f and upon $R_a = AR_1$ is shown.

$$\frac{\delta R_n}{R_n} = \frac{1}{1 + \frac{R_f}{R_a}} \cdot \frac{\delta R_f}{R_f} + \frac{R_n}{R_a}\left[\left(\frac{\delta R_a}{R_a}\right)_i + \left(\frac{\delta R_a}{R_a}\right)_v + \left(\frac{\delta R_a}{R_a}\right)_t\right]. \tag{25}$$

The subscripts i, v, and t refer to interchangeability, voltage, and temperature respectively. From both design and experimental data, the components of (25) have been derived and the result is plotted in Fig. 11. This degree of stability is representative of a practicable design and is entirely adequate for the switching application described in this paper. For more demanding applications, greater stability is readily achievable. The environmental conditions which apply to the data in Fig. 11 include interchangeability of units, voltage variation between 25 and 31 volts and temperature variations from -50°C to $+75$°C.

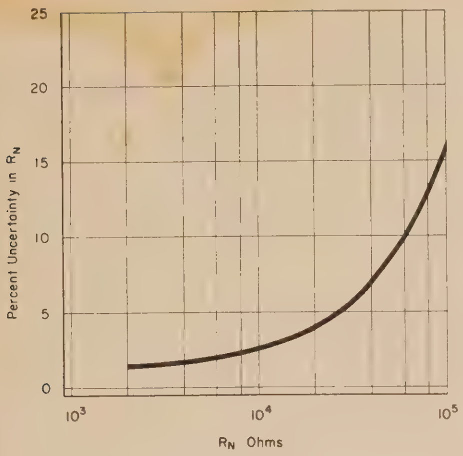

Fig. 11—Per cent uncertainty in R_n.

VI. SENSOR DESIGN

The basic element of the sensor is a piece of natural crystalline quartz, x cut ($+5°$) which vibrates in a direction approximately parallel to the longest axis. It is approximately one inch long and radiates acoustic energy from both end surfaces.

The quartz plate is supported by four leads, two pairs on each major surface. The leads are headed beryllium copper wires, vacuum heat treated, gold plated and bonded to the quartz surface by epoxy resin. The leads are mounted off the nodal line which runs between the leads and approximately normal to the long axis of the crystal. This location of the leads provides an excellent mechanical mounting by providing a supporting couple about the axis of greatest moment of inertia. The lead length is chosen to provide a broad resonance around the vibrating frequency ($\sim$100 kc), and a correspondingly low mechanical impedance at the crystal surface. The mounting permits Q's of 30,000 or so. A general view of one version of this design is shown in Fig. 12, and Fig. 13 is a magnified view of the support lead attachment to the crystal surface. The unit shown in Fig. 12 has electrodes of silver. Another version suitable for corrosive fluids is geometrically similar but platinum has been substituted for silver, metal bonding for epoxy resin, etc. These designs are very rugged and will withstand and operate under sinusoidal accelerations of 25 g at frequencies up to 2000 cycles.

VII. ELECTRONIC UNIT DESIGN

A model of one design of the electronic unit is shown in Fig. 14. The amplifier portion comprises three transistor stages having a total gain of 72 db. By choice of value of resistor R_f, it is capable of generating negative resistances between about 1500 and 200,000 ohms. Both transistor and relay-type control circuits have been used with this type of amplifier. The model shown includes a control circuit comprising a single transistor dc

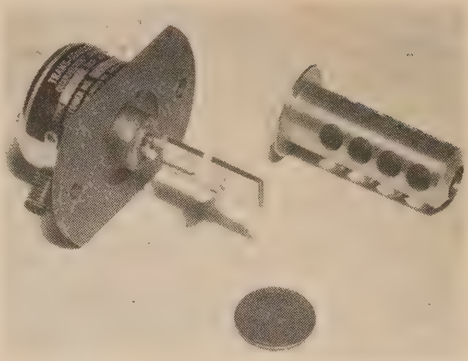

Fig. 12—"In tank" sensor, cage removed.

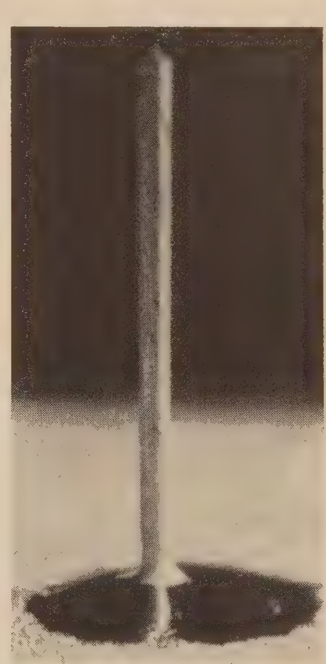

Fig. 13—Support lead attachment to crystal surface about 25×.

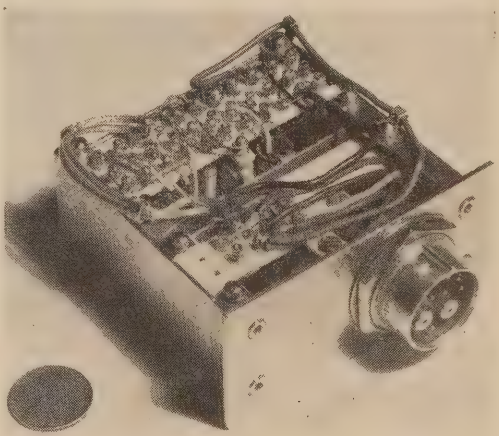

Fig. 14—Model of electronic unit without case.

amplifier and a relay. The production units of the same design are interchangeable and may be used without adjustment with arbitrary cable lengths between electronic unit and sensor from 0 to 250 feet.

VIII. Conclusion

A thoroughly reliable and highly discriminating technique for distinguishing between liquid and gaseous phases of fluids has been described. Conditions of splashing and a wet sensor in gas are easily distinguished from the in-liquid conditions. The components and the phenomenon are compatible with a wide variety of fluids including cryogenic propellants. The technique used includes the stable generation of negative resistance and provides a technique for the measurement of radiation resistance which may have additional applications.

IX. Acknowledgment

The authors acknowledge the contributions of V. C. Westcott, who originally suggested the idea of utilizing the damping of a crystal when immersed in a liquid, and of R. Arsenault, J. Meyer, and J. Middleton, who have contributed to the design, construction, and testing of the equipments described here, and of Prof. R. B. Belser of Georgia Institute of Technology for the photograph in Fig. 13.

An Instrument for Measuring Liquid Level and Slosh in the Tanks of a Liquid-Propellant Rocket*

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Summary—**A measuring system for monitoring dynamic level variations in red fuming nitric acid is discussed. The system employs a continuous variable-capacitance sensor with a tuned-circuit capacitance detector. The transistorized, temperature-stabilized capacitance detector is discussed in detail. Performance data are presented.**

Background

As part of the diagnostic instrumentation for use in the development of liquid fuel rockets, an instrument was required which could monitor the level and surface attitude in the rocket propellant tanks. The original requirement written for this instrument was for monitoring only an oxidizer, red fuming nitric acid. It is only this instrument, called the Oxidizer Slosh Monitor, which will be discussed here.

Before proceeding further, it is worthwhile to consider the properties of the material in which the monitor was to function. Red fuming nitric acid is a liquid, slightly more dense and slightly more viscous than water. Extremely corrosive, it reacts with most organics and dissolves most metals, though at varying rates. Electrically, the acid is about as conductive as a saturated salt solution, but the conductivity of acid acceptable as propellant varies over a considerable range.

The device for monitoring this material was to provide a continuous measure of level along three or more lines up and down the curved wall of a tank. Thus, at any time, the mean level and the attitude of the liquid surface relative to the rocket axis might be determined, assuming the liquid surface remained a plane. Because sloshing of the propellant might be of great importance in diagnosing a rocket failure, the monitor had to be capable of following level oscillations up to 3 cps.

One of the first techniques tried in developing a monitor was the use of a high-resistance wire, shorted to the tank wall by the liquid at the liquid surface and below. As so often happens with such simple techniques there were unforeseen complications. Specifically, the action of the acid on the wire made its resistance change and interfered with the electrical contact between the wire and the liquid.

To avoid the effects of acid reacting with the metal wire, an insulating material was interposed between the wire and the acid, changing the sensor to a capacitive element similar to those used in wave gages.[1–3] Various insulating materials were tried, and it was found that of the materials tried, only fused Kel-F insulation retained its electrical properties when immersed in nitric acid.

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* Original manuscript received by the IRE, December 2, 1959. Work performed under Air Force Contract AF04(647)-347.

† Missiles and Space Div., Lockheed Aircraft Corp., Palo Alto, Calif.

[1] W. S. Campbell, "An Electronic Wave-Height Measuring Apparatus," David Taylor Model Basin, Washington, D. C., Rept. No. 859; October, 1953.

[2] G. R. Barnard, "An Evaluation of Wave-Height Measuring Equipments," Instrumentation Div., David Taylor Model Basin, Washington, D. C., Tech. Note No. 9; September, 1958.

[3] C. G. Whittenbury, E. A. Huber, and G. S. Newell, "Instrument for measuring water waves," *Rev. Sci. Instr.*, vol. 30, pp. 674–677; August, 1959.

THE CAPACITIVE SENSOR

The sensing element which was used for the Oxidizer Slosh Monitor was a length of wire, insulated with Kel-F, strung in a vertical plane on Teflon stand-offs along the curved wall of the oxidizer (acid) tank. When immersed in the acid, this wire formed a capacitor of which the insulation was the dielectric, the wire was one "plate," and the acid at the outside surface of the insulation was the other "plate." Above the surface of the acid, the wire and the tank wall formed a capacitor of much lower value. Thus, in effect, the sensor was a cylindrical capacitor, the length of which was determined by the oxidizer level.

Typical capacitance values for this sensor were 0.5 $\mu\mu$f/inch between dry wire and the tank wall, and 3.5 $\mu\mu$f/inch for the immersed wire. In the frequency range used (below 5 mc), the impedance of this capacitance was such that the resistance of the acid was comparatively small, and the resistance of the wire was negligible.

FLOWBACK

When the liquid level was oscillating (*i.e.*, under sloshing conditions), the liquid in the immediate vicinity of the sensor wire did not follow perfectly the mean liquid level. Instead, a film of liquid clung to the sensor, causing a phenomenon known as flowback.[1,2] Fig. 1 illustrates graphically the flowback film and its effect on the apparent capacitance of the sensor element. As indicated by the figure, some of the sensor wire actually above the level of the liquid remained electrically connected to the liquid by the flowback film. For a sinusoidal variation of liquid level, the effect of flowback on sensor capacitance, hence on instrument output, was to decrease peak-to-peak amplitude, shift the phase, and distort the waveform by flattening one peak, sharpening the other.

The most serious effect of flowback on the Oxidizer Slosh Monitor was the attenuation of slosh amplitude. For slosh amplitude of the order of a few inches, the attenuation from flowback exceeded 60 per cent at a frequency of only 2 cps in some early models. The attenuation from flowback was aggravated when the mean liquid level crossed a sensor wire support. The wire supports would catch a quantity of liquid at the peak of a slosh and drip it down the sensor wire throughout the rest of the slosh cycle, essentially obscuring the variation of the main liquid surface.

MEANS OF MINIMIZING FLOWBACK

The effects of flowback on slosh frequency response were found to be dependent on at least two variables, the sensor wire diameter and the carrier frequency at which the sensor capacitance was measured.

It was found that as sensor wire diameter was decreased, the slosh frequency response was improved. This effect resulted from the utilization of surface tension to dissipate the flowback film. Unfortunately, the slosh monitor application did not permit the use of a very fine wire. The wire had to be installed in hard to reach places and fed out through a large lid. The mortality on AWG No. 36 wires, which were tried first, was discouragingly high. An AWG No. 30 wire has been used in the more recent applications, although the diameter is somewhat large to make good use of surface tension effects.

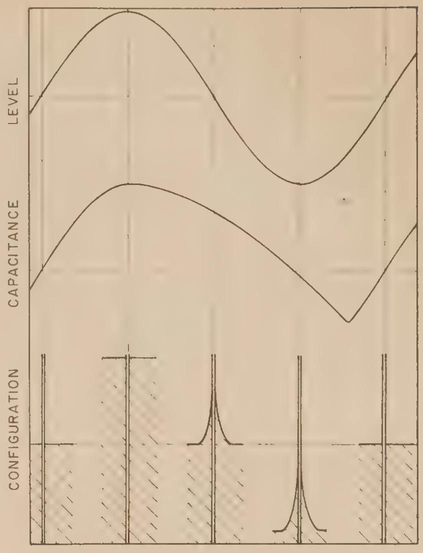

Fig. 1—Flowback and its effect on the output of a variable-capacitance level sensor.

By varying the carrier frequency at which the sensor capacitance was measured, it was possible to differentiate somewhat between wire immersed in the liquid and wire which was only wetted by a flowback film. An element of sensor wire wetted by a flowback film differed electrically from a completely immersed element by having in series with it the resistance of the flowback film. By increasing the carrier frequency, the capacitive impedance of that element could be decreased so that it might be effectively excluded from the circuit by the series resistance of the flowback film.

This principle of differentiating flowback and main level was applied to the Oxidizer Slosh Monitor by increasing the carrier frequency to 3 mc. The carrier frequency was more or less limited at this value because the required length of sensor, acting as a transmission line, became an appreciable fraction of a wavelength at 3 mc.

The use of the 3-mc carrier gave the Oxidizer Slosh Monitor an acceptable slosh frequency response despite the use of relatively large wire (see "Performance" section). However, no means was found of eliminating the degradation of slosh response caused by wire supports in the slosh.

THE ELECTRONICS

Detection of the capacitive changes of the sensor wire is somewhat complicated by the necessity of making measurements at 3 mc. Wide variances in sensor capacitance, the balancing problems and high power levels associated with the majority of capacitive measuring techniques, led to a selection of a slope detection system. This system provided a means of determining, with reasonable linearity, the variation in capacitance with a minimum power consumption. Fig. 2 shows the resultant system in block form.

A crystal-controlled oscillator was selected to afford maximum frequency stability and minimum temperature dependence. The frequency of the oscillator was held constant by the crystal and thereby one variable was eliminated from the system. As a means of eliminating the oscillator amplitude as a variable, a clamp circuit was provided which limited the peak-to-peak amplitude to a fixed value over the environmental range of the equipment. In this manner the input to the slope detector was held constant in frequency and amplitude.

Amplitude dependence on sensor capacitance was developed by use of a tuned circuit which acted as a variable impedance in a voltage divider circuit. The resonant circuit consisted of a transformer which was resonated slightly above the crystal frequency when the sensor capacitance was maximum (the full-tank condition). As the sensor capacitance decreased, the resonant frequency of the transformer increased and the signal amplitude at the resonant circuit decreased. The linearity and capacitance range of the resonant circuit was controlled by the turns ratio of the transformer and the series-parallel capacitor network used in conjunction with the sensor.

Capacitance data in the form of variable amplitude of the 3-mc carrier frequency are converted to a usable form by peak-to-peak detection in a thermistor temperature-compensated detector. The resulting slowly varying dc voltage, dependent on sensor capacitance, was made suitable for injection into a conventional telemetry system by use of an emitter-follower output for impedance matching. Since the output is dependent upon the resonant circuit characteristic curve, it is not linear over the entire range, and therefore a calibration curve was required to convert from dc output voltage to tank liquid level. A circuit diagram of the completed system is shown in Fig. 3.

Performance

The Oxidizer Slosh Monitors which have been built and tested provided acceptable, but not ideal, performance. The response to static level was not linear, but was an "S" curve for which deviation from linearity was less than 5 per cent over the range used. (See Fig. 4.) Typical repeatability of indicated level information over a temperature range of +10°C to +50°C was 1.5 per cent of full scale. The ratio of full-tank output to empty-tank output was about 10:1, which did not approach the 30:1 ratio which the telemetry could accept, but was enough to provide clear definition of level throughout the range. Because of the deviation of the output/level curve from linearity, the sensitivity of the monitor to slosh was different at different liquid levels.

The effects of flowback were not completely eliminated from the system. The output for a 3-inch slosh amplitude declined by about 25 per cent at 3 cps, more at higher frequencies. (See Fig. 5.)

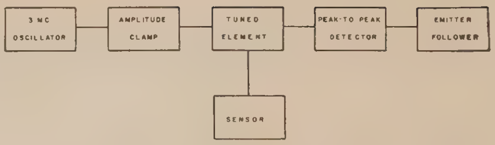

Fig. 2—Block diagram of the Oxidizer Slosh Monitor.

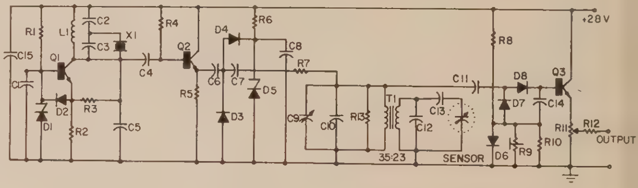

Fig. 3—Circuit schematic of the Oxidizer Slosh Monitor.

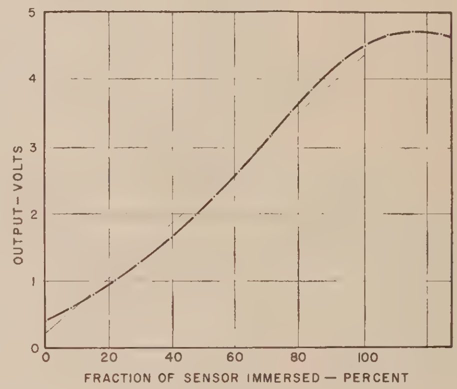

Fig. 4—Output vs sensor immersion for the Oxidizer Slosh Monitor.

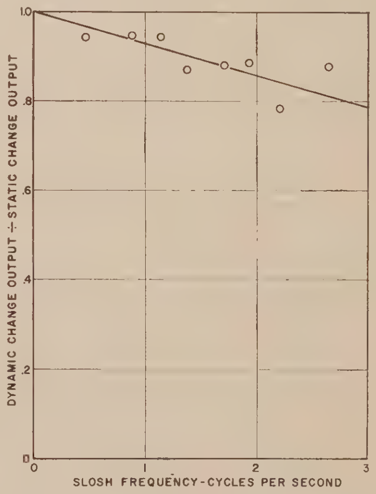

Fig. 5—Slosh frequency response of the monitor in red fuming nitric acid.

Acknowledgment

The authors wish to acknowledge the guidance of Dr. T. A. Perls in developing the concept of the slosh monitor, and the craftsmanship of J. L. Hatchel and H. L. Koehl in assembling the prototype models.

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Noise Performance Theory of Esaki (Tunnel) Diode Amplifiers*

In a recent letter, K. K. N. Chang[1] described an amplifier using the Esaki Diode. He presented expressions for the gain g_p and noise figure F of a two-port circuit with separate generator and load impedances. These expressions are

$$g_p = \frac{4G_gG_L}{(G_L + G_g + G_1 - G)^2} \tag{1}$$

and

$$F = 1 + \frac{T}{T_0}\left(\frac{G_1}{G_g} + \frac{G_L}{G_g} + \frac{G_e}{G_g}\right). \tag{2}$$

In the above, T is the circuit temperature; T_0 is the reference temperature; G is the diode negative conductance; G_g is the source generator conductance; G_1 is a parasitic circuit-loss conductance; G_L is the load conductance; and G_e is an artificial electronic conductance $eI_0/2kT$ in which I_0 is the direct current of the diode, k is Boltzmann's constant and e is the electronic charge. (Chang also included a transformer turns-ratio which appeared in his circuit. This has been eliminated as unnecessary to the theory. If transformers are to be used, they can be considered to modify the values of G_L and G_g, but not G_1 as this parasitic resistance tends to be associated with the diode itself.) The above expression for noise figure is based upon the assumption that the diode is characterized by pure shot noise and that the resistances are sources of thermal noise only.

Direct application of (2) indicates that a very low noise figure could be obtained by raising G_g to a large value. This, however, cannot be done without considering the effect upon gain, which depends upon the negative conductance G, a parameter not included in (2). When this effect is taken into account it will be seen that useful low-noise amplification depends upon obtaining a low value for the ratio $eI_0/2kTG$ and for the ratio G_1/G. In Chang's discussion in his letter and in his paper at WESCON, 1959, he also implies that $eI_0/2kTG$ is the most important parameter but does not show the manner in which this expression appears.

We shall present here an analysis of the one-port form of amplifier which is, in general, superior to the two-port variety for low noise. Fig. 1 shows the circulator method of interconnecting one-port amplifiers. Fig. 2 shows a simplified equivalent circuit for a single amplifier and its connecting transmission line. If a transformer is to be used it should be at the input of this circuit, which has the effect of allowing G_g to assume any desired value as far as this analysis is concerned.

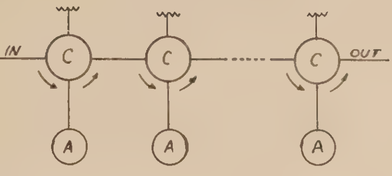

Fig. 1—Tandem arrangement of one-port amplifier A and circulators C.

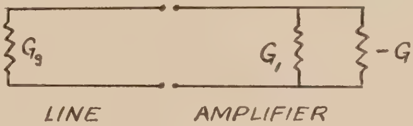

Fig. 2—Simplified equivalent circuit of one-port amplifiers.

The gain of the one-port amplifier is given by the square of the magnitude of the reflection coefficient on the input line. This is

$$g_p = \left[\frac{G_g - G_1 + G}{G_g + G_1 - G}\right]^2, \tag{3}$$

and the noise figure (for the above assumptions) is

$$(F)_{\text{one port}} = 1 + \frac{4T}{T_0}\,G_gG\,\frac{\left(\frac{eI_0}{2kTG} + \frac{G_1}{G}\right)}{(G_g - G_1 + G)^2}. \tag{4}$$

where M is the "noise measure" of one stage defined by Haus and Adler[2] as

$$M = \frac{F - 1}{1 - \frac{1}{g_p}}. \tag{7}$$

Thus the net noise figure for n stages becomes

$$(F)_{n\text{ stages one port}} = 1 + \frac{T}{T_0}\left[\frac{1 - \frac{1}{g_p{}^n}}{1 - \frac{G_1}{G}}\right]\left(\frac{eI_0}{2kTG} + \frac{G_1}{G}\right). \tag{8}$$

In this expression G_g does not appear except indirectly in that it affects the gain of a single stage and the number of amplifiers required for a given system gain. When the total gain of n stages is high, it is seen that the over-all noise figure for many low-gain stages is the same as for a single high-gain stage.

We can devise a similar expression for a tandem arrangement of two-port amplifiers using (2). In order to minimize M, we have set

$$G_g = G_L + G - G_1. \tag{9}$$

We have also assumed that the stages are separated by isolators at a temperature T. The resulting over-all noise figure expression becomes

$$(F)_{n\text{ stages two port}} = 1 + \frac{T}{T_0}\left[\frac{1 - \frac{1}{g_p{}^n}}{1 - \frac{G_1}{G}}\right]\left(\frac{eI_0}{2kTG} + \frac{G_1}{G} + \frac{G_L}{G}\right). \tag{10}$$

As in (2) we can make $(F-1)$ approach zero by allowing G_g to become arbitrarily large. This, however, is no help because the gain is reduced in the process and then several stages may be needed, each of which contributes to the over-all noise figure of the system. Consider (4) when the gain is high. Then G_g approaches $(G-G_1)$ and the expression becomes

$$(F)_{\text{high gain one port}} = 1 + \frac{T}{T_0}\left[\frac{1}{1 - \frac{G_1}{G}}\right]\left(\frac{eI_0}{2kTG} + \frac{G_1}{G}\right). \tag{5}$$

If the gain is not high we must consider two or more stages in tandem. In this case, the over-all noise figure for n stages can be written

$$(F)_{n\text{ stages}} = 1 + M\left(1 - \frac{1}{g_p{}^n}\right), \tag{6}$$

If we substitute (9) into Chang's gain expression (1), we obtain

$$g_p = 1 + \frac{G}{G_L} - \frac{G_1}{G_L}. \tag{11}$$

If we wish to obtain a low over-all noise figure, (10) indicates that G_L/G must be small, and from (11) this implies that the gain of each stage must be high. Thus, the two-port amplifier can give good noise performance only if the gain is high and the load conductance G_L small. As G_L appears in the numerator of the gain expression (1), this requires the denominator to be small indeed and we must work close to the point of instability. This will also reduce the bandwidth. With two-port amplifiers it is possible, theoretically, to approach the noise performance of one-port amplifiers but only by sacrificing stability and bandwidth.

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* Received by the IRE, September 17, 1959.

[1] K. K. N. Chang, "Low-noise tunnel-diode amplifier," Proc. IRE, vol. 47, pp. 1268–1269; July, 1959.

[2] Haus and Adler, "Circuit Theory of Linear Noisy Networks," John Wiley and Sons, Inc., New York, N. Y.; 1959.

Firing Angle in Series-Connected Saturable Reactor*

H. F. Storm[1] has discussed the series-connected saturable reactor with free even harmonics (see Fig. 1). He states that in the overexcited case, the firing angle α remains constant for a range of values of the control voltage E_c. However, he does not prove this. In a letter to the author, Storm stated he is not aware of any proof of this being published. It is the purpose of this letter to derive the proof.

Consider Fig. 2. During the interval $\omega t<2\pi$, the control voltage $E_c=0$, and so the flux curves of ϕ_A and $-\phi_B$ coincide. At $\omega t=2\pi$, a small control voltage is introduced. Both cores will tend to saturate, but core A will tend to saturate more quickly now than before E_c was applied, and core B more slowly. Thus, core A will saturate at an angle α while core B is as yet unsaturated.

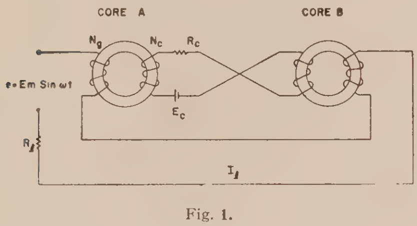

Fig. 1.

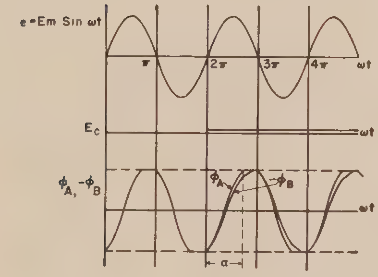

Fig. 2.

The angle α can be determined from (1)

$$2\phi_s = \frac{1}{\omega}\int_0^\alpha \left(\frac{E_m \sin \omega t}{2N_g} + \frac{E_c}{2N_c}\right) d(\omega t) \tag{1}$$

where ϕ_s is the saturation flux of the cores.

Core B will continue toward saturation after core A has become saturated. Depending on the value of E_c, it may or may not saturate during the course of the half cycle (180°). Let us determine the conditions under which core B will saturate at the very end of the half cycle. During the interval that core A is as yet unsaturated, $2\pi<\omega t<\alpha$, the flux in core B will change by an amount given by

$$\Delta\phi_1 = \frac{1}{\omega}\int_0^\alpha \left(\frac{E_m \sin \omega t}{2N_g} - \frac{E_c}{2N_c}\right) d(\omega t). \tag{2}$$

When core A is saturated, the voltage across its primary is zero. Core B acts as a transformer with a secondary resistance R_c. The voltage across the primary of core B is therefore given by

$$E_B = \frac{R_c\left(\dfrac{N_g}{N_c}\right)^2}{R_l + R_c\left(\dfrac{N_g}{N_c}\right)^2} E_m \sin \omega t$$

$$\approx \frac{R_c}{R_l}\left(\frac{N_g}{N_c}\right)^2 E_m \sin \omega t \tag{3}$$

The above approximation is based on the assumption that

$$R_c\left(\frac{N_g}{N_c}\right)^2 \ll R_l. \tag{4}$$

During the interval that core A is saturated, the change in the flux of core B is given by

$$\Delta\phi_2 = \frac{1}{\omega}\int_\alpha^\pi \left[\frac{E_m}{N_g}\,\frac{R_c}{R_l}\left(\frac{N_g}{N_c}\right)^2 \sin \omega t - \frac{E_c}{N_c}\right] d(\omega t). \tag{5}$$

When E_c is adjusted so that core B saturates at the very end of the half cycle, we have

$$\Delta\phi_1 + \Delta\phi_2 = 2\phi_s. \tag{6}$$

Integrating and then combining the above equations, using the approximation of (4) again, and defining the voltage E_{ms} by (7)

$$E_{ms} = 2N_g\phi_s\omega. \tag{7}$$

We finally obtain

$$E_c = 2(E_m - E_{ms})\,\frac{R_cN_g}{R_0N_c\pi}\cdot \tag{8}$$

Thus, as long as E_c does not exceed the value given in (8), α will be independent of E_c.

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* Received by the IRE, September 14, 1959.

[1] H. F. Storm, "Magnetic Amplifiers," John Wiley and Sons, Inc., New York, N. Y.; 1955.

Harmonic Generation Using Idling Circuits*

Manley and Rowe[1] have treated the case of mixing and harmonic generation by a nonlinear reactance. They show that for the latter case

$$\sum_{m=1}^{\infty} W_{m,0} = 0 \tag{1}$$

where $W_{m,0}$ is the algebraic power delivered to the nonlinear reactance of frequency mf_1; the fundamental frequency is f_1. In practice, one is interested in converting from frequency f_1 to a harmonic kf_1. It is commonly believed that this is automatically accomplished by terminating all circuits reactively except those of frequencies f_1 and kf_1.

The purpose of this note is to show that:

1) conversion to an arbitrary order of harmonic requires additional criteria on the order of the nonlinearity of the frequency converting element;
2) by terminating additional circuits resistively in such a way as to allow large circulation of energy at additional frequencies, it is possible to increase the order of the harmonic that can be generated over that allowed by the two-circuit system.

The schematic diagram of a harmonic generator using an element with a square-law characteristic is shown in Fig. 1. Here the two loops are tuned to resonance at frequencies ω and $k\omega$, respectively. They are coupled by a nonlinear inductance whose characteristic is given by

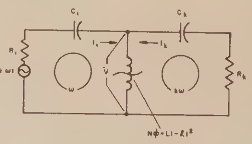

Fig. 1—Two-loop harmonic generator.

$$N\phi = Li - \mathfrak{L}i^2, \tag{2}$$

where ϕ and i are the instantaneous deviations of flux and current from those of a static operating point. The voltage across the nonlinear element is then

$$V = L\frac{di}{dt} - 2\mathfrak{L}i\,\frac{di}{dt}, \tag{3}$$

where the second term on the right is the one of importance for harmonic generation. If the circuit Q's are high (a requirement for efficient harmonic generation),[2] then the currents in the two meshes may be expressed as

$$i_1 = I_1 \sin(\omega t + \theta_1)$$
$$i_k = I_k \sin(k\omega t + \theta_k). \tag{4}$$

Since $i=i_1+i_k$, the second term in (3) becomes

$$\begin{aligned}-2\mathfrak{L}i\,\frac{di}{dt} = &-I_1{}^2\mathfrak{L}\omega \sin(2\omega t + 2\theta_1)\\ &-I_1Ik\mathfrak{L}_k\omega \sin\left[(k+1)\omega t+\theta_1+\theta_k\right]\\ &+I_1Ik\mathfrak{L}_k\omega \sin\left[(k-1)\omega t+\theta_k-\theta_1\right]\\ &-I_1I_k\mathfrak{L}\omega \sin\left[(k+1)\omega t+\theta_k+\theta_1\right]\\ &-I_1I_k\mathfrak{L}\omega \sin\left[(k-1)\omega t+\theta_k-\theta_1\right]\\ &-I_k{}^2\mathfrak{L}k\omega \sin(2k\omega t + 2\theta_k).\end{aligned} \tag{5}$$

If power transfer from the "ω" circuit to the "$k\omega$" circuit is to occur, terms of frequency ω and $k\omega$ must exist simultaneously in this expression. The frequencies present are

$$2\omega,\ 2k\omega,\ (k+1)\omega,\ (k-1)\omega.$$

We see that coupling can exist only for two values of k *viz.*, $k=1$ (trivial) and $k=2$.

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* Received by the IRE, December 18, 1959.

[1] J. M. Manley and H. E. Rowe, "Some general properties of nonlinear elements," PROC. IRE, vol. 44, pp. 904–913; July, 1956.

[2] K. K. N. Chang, "Harmonic generation with non-linear reactances," *RCA Rev.*, vol. 19, pp. 455–464; September, 1958.

Therefore, such a circuit using a square-law element will produce negligible amounts of harmonic outputs of order higher than the second.

If the circuit Q's are low, the current in each loop will not be restricted to only the resonant frequency of that loop. The additional components will mix in the nonlinear reactance to produce power at higher harmonics. This power will be very small.

However, appreciable amounts of power at the third or fourth or even higher harmonics can be achieved by the addition of an idling circuit to the basic two-loop configuration, as shown in Fig. 2. With this scheme, energy is transferred to the 3ω loop as the result of the mixing of current at the fundamental frequency with that produced in a resonant "idler" at 2ω. We have analyzed this circuit as well as the similar ω-2ω-4ω circuit, following the method of Bloom and Chang.[3] The current in the fundamental loop in both cases obeys a fifth-degree algebraic equation. For the 3ω case, the equation is

$$\left(\frac{I_1}{i_0}\right)^5\left[\frac{9}{Q_3}+\frac{36}{Q_1}\right]-\frac{36}{Q_0}\left(\frac{I_1}{i_0}\right)^4+\left[\frac{48}{Q_1Q_2Q_3}+\frac{4}{Q_2Q_3{}^2}\right]\left(\frac{I_1}{i_0}\right)^3-\frac{48}{Q_0Q_2Q_3}\left(\frac{I_1}{i_0}\right)^2+\frac{16}{Q_1Q_2{}^2Q_3{}^2}\left(\frac{I_1}{i_0}\right)-\frac{16}{Q_0Q_2{}^2Q_3{}^2}=0, \tag{6}$$

where

$$i_0=\frac{L}{2\mathfrak{L}};\quad Q_j=\frac{\omega L}{R_j}\ (j=0,1,2,3);$$

$$R_0=V/i_0.$$

For the 4ω case:

$$\left(\frac{I_1}{i_0}\right)^5+\left[\frac{4}{Q_1Q_2}+\frac{16Q_4}{Q_1{}^3}\right]\left(\frac{I_1}{i_0}\right)^3-\left[\frac{4}{Q_0Q_2}+\frac{48Q_4}{Q_0Q_1{}^2}\right]\left(\frac{I_1}{i_0}\right)^2+\frac{48Q_4}{Q_0{}^2Q_1}\left(\frac{I_1}{i_0}\right)-\frac{16Q_4}{Q_0{}^3}=0. \tag{7}$$

Figs. 3 and 4 illustrate representative cases for the third and fourth harmonic conversion, where the efficiency η is defined as

$$\eta=\frac{\text{output power at } k\omega}{\text{total input power}}.$$

In general, these as well as other data show that the efficiency increases with circuit Q's and input voltage. Of course, the efficiency is limited by the maximum allowable current in the element, as would also be true in a simple converter.

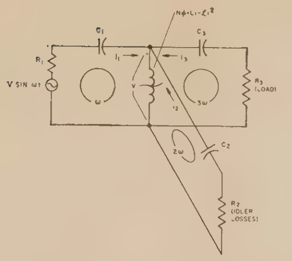

Fig. 2—Harmonic generator with idler.

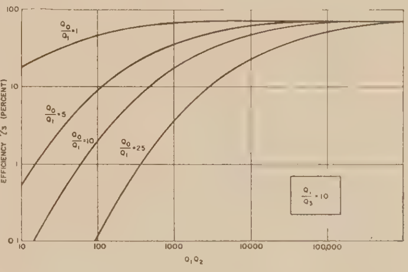

Fig. 3—Efficiency of 3ω conversion vs circuit parameters.

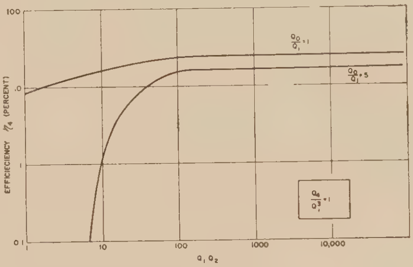

Fig. 4—Efficiency of 4ω conversion vs circuit parameters.

Experimental work which substantiates these results was performed at audio frequencies. To simulate an element which was nearly square law, a toroidal inductor was current-biased to a square-law region. The insertion of this inductor into a two-loop circuit yielded only the second harmonic of the fundamental 1000-cycle signal. When the output loop was tuned to either 3ω or 4ω, no measurable output was present. Operation of the same element in the three-loop circuit (ω, 2ω, 3ω, or ω, 2ω, 4ω) with the same driving voltage yielded considerable amounts of third (or fourth) harmonic power. Table I shows a comparison between the theoretical and experimental results.

TABLE I

Three-loop circuit	Q_0	Q_1	Q_2	Q_3	Q_4	Experimental I_1/i_0	Theoretical I_1/i_0	Experimental η_3	Theoretical η_3	Experimental η_4	Theoretical η_4
ω-2ω-3ω	4.50	2.86	1.44	0.751	—	0.641	0.520	8.5 per cent	7.2 per cent	—	—
ω-2ω-4ω	4.8	2.9	1.5	—	8.86	0.790	0.490	—	—	3.0 per cent	0.57 per cent

The deviations between the theoretical and experimental values are probably due to the following: 1) the assumption that current at $n\omega$ flows only in the $n\omega$ loop was not strictly true because of low Q's; and 2) in the calculation of the efficiencies, it was necessary to raise to a power the difference between two numbers of nearly equal magnitude.

The work reported here has treated only a square-law device. Enhancement of the third harmonic generated by a ferrite at microwave frequencies using this general feedback scheme has recently been reported.[4] For elements that have nonlinearities higher than the second, such as the back-biased diode, efficient conversion to a higher harmonic is of course possible with the two-loop circuit. However, even here the efficiency should be improved by resistively terminating additional branches of the Manley-Rowe circuit, as described above.

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[3] S. Bloom and K. K. N. Chang, "Theory of parametric amplification," *RCA Rev.*, vol. 18, pp. 578–593; December, 1957.

[4] E. N. Skomal and M. A. Medina, "Study of a microwave ferrimagnetic multiple signal conversion process," *J. Appl. Phys.*, vol. 30 (suppl.), pp. 161S–162S; April, 1959.

Solid State Generator for 2×10^{-10} Second Pulses*

Oscillograms showing pulses having indicated base durations as short as 2×10^{-10} seconds have been obtained using an improved version of the diffused silicon mesa diode described by Forster and Zuk.[1]

The diode under test is mounted in shunt of a 50-ohm coaxial line with provision for dc bias as shown in the schematic, Fig. 1. In this application the diode is biased in the forward direction. A 20-mc generator drives the diode with positive pulses of approximately 10^{-8} seconds duration at the base. A sharp step is produced on the trailing edge of the generator pulses by the action of the shunt diode at about the time the diode stops conducting. The differentiating stub

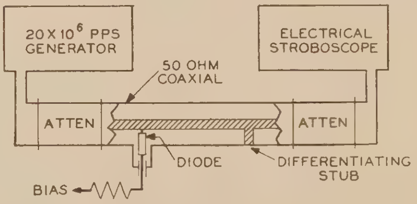

Fig. 1—Block schematic for pulse generator.

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* Received by the IRE, January 13, 1960.

[1] J. H. Forster and P. Zuk, "Millimicrosecond diffused silicon computer diodes," 1958 WESCON Convention Record, pt. 3, pp. 122–130.

translates the step voltage into the 2×10^{-10} second pulse shown in the oscillogram of Fig. 2. This pulse has an amplitude of 0.5 volt and a repetition rate of 20 mc.

An example of a sharp voltage step is shown in Fig. 3. In this case the sharp step was produced by an 80-mc sine wave generator instead of the 20-mc pulse generator.

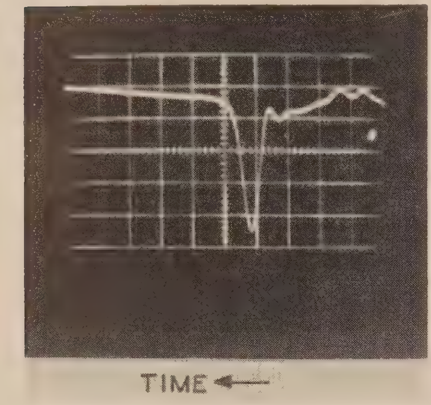

Fig. 2—20-mc pulse, base duration 2×10^{-10} seconds, amplitude 0.5 volt.

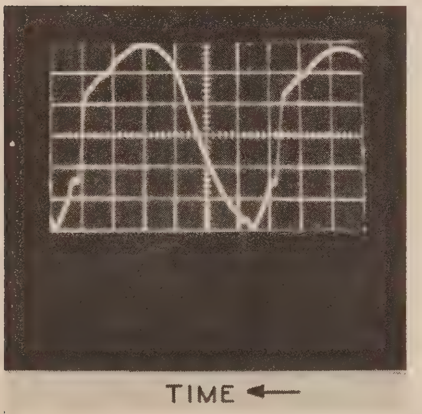

Fig. 3—80-mc sine wave with step, peak to-peak signal 3 volts.

Either the sharp steps or the short pulses can be produced at any repetition rate up to several hundred million per second and there appears to be no limit to the low frequency repetition rate. In other words, a single pulse of approximately 10^{-10} seconds duration can be produced provided that an appropriate single driving pulse is available.

These oscillograms were made using the "fractional millimicrosecond electrical stroboscope" which will be described elsewhere.[2]

We wish to thank J. H. Forster of the Bell Telephone Laboratories for supplying us with the special computing diodes used in these experiments.

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[2] W. M. Goodall and A. F. Dietrich, "Fractional Millimicrosecond Electric Stroboscope," submitted to PROC. IRE.

Extension of Longitudinal-Beam Parametric-Amplifier Theory*

The longitudinal-beam parametric amplifier has been previously investigated[1,2] using a model in which coupling between only the lower sideband and the signal was considered. Experiments by Ashkin, *et al.*[3] which showed large discrepancies between theoretical and measured values of gain, raised the question as to whether or not the original model accurately described the system. Another model which had been used in study of high-frequency beam modulations of traveling-wave tubes is now proposed. In the latter model, coupling is allowed between the signal and the first upper and lower sidebands around the fundamental of the pump frequency. The coupling to the sidebands around the second harmonic of the pump may be an important factor; however, this is neglected in the present study.

The assumptions made in this "multimode" theory are very similar to those used by Louisell and Quate;[1] that is, the pump frequency is twice the signal frequency, only one space-charge wave (either fast *or* slow) is excited at each frequency, and the pump amplitude is much greater than the sideband and signal amplitudes. All amplitudes are assumed much less than the beam average quantities. Under these conditions the pump signal will propagate unperturbed with a wave number

$$\beta_e\left(1-\frac{a'\omega_q}{\omega}\right),$$

where

$$a'=\frac{\omega_{q2}}{2\omega_q}=\frac{\text{reduced plasma frequency at pump frequency}}{2x\text{ reduced plasma frequency at signal frequency}},\tag{1}$$

and $a'>0$ for the fast wave and $a'<0$ for the slow wave. Introduce the following definitions:

$$b'=\frac{\omega_{q3}}{3\omega_q}=\frac{\text{reduced plasma frequency at upper sideband}}{3x\text{ reduced plasma frequency at signal frequency}}\tag{2}$$

$$m=|m|e^{j\phi}=\frac{i}{I_0}=\begin{array}{l}\text{complex modulation}\\ \text{index of pump}\\ \text{excitation,}\end{array}\tag{3}$$

where i is component of RF convection current at the pump frequency and I_0 is the average beam current. Also v_1 is defined as the velocity at the signal frequency, v_{11} as the velocity at the upper sideband and, finally, $\beta_q=\omega_q/u_0$ as the reduced plasma frequency radian wave number. Assume that the velocities can be described by

$$v_1=u_1(z)\exp-j\beta_e\left(1-\frac{a'\omega_q}{\omega}\right)z,$$

$$v_{11}=u_{11}(z)\exp-3j\beta_e\left(1-\frac{a'\omega_q}{\omega}\right)z.\tag{4}$$

The propagation at the sideband frequencies can then be described in terms of the velocity amplitudes by two simultaneous linear differential equations:

$$\begin{aligned}&\frac{d^2u_1}{dz^2}+2j\beta_qa'\frac{du_1}{dz}\\&\quad-\beta_q{}^2\left[a'^2\left(1+\frac{|m|^2}{4}\right)\right.\\&\quad\left.-1+\frac{a'^2}{b'^2}\frac{|m|^2}{4}\right]u_1\\&\quad-\beta_q{}^2\frac{m}{2}(1+2a'^2)u_1{}^*\\&\quad+j\beta_qa'\frac{m^*}{2}\left[1+\frac{1}{3b'^2}\right]\frac{du_{11}}{dz}\\&\quad-\beta_q{}^2\frac{m^*}{2}\left[1+a'^2\left(1+\frac{1}{b'^2}\right)\right]u_{11}\\&\quad-a'^2\beta_q{}^2\frac{m^2}{4}u_{11}{}^*=0\end{aligned}\tag{5}$$

and

$$\begin{aligned}&\frac{d^2u_{11}}{dz}+6j\beta_qa'\frac{du_{11}}{dz}\\&\quad-9\beta_q{}^2\left[a'^2(1+b'^2)\frac{|m|^2}{4}-b'^2\right]u_{11}\\&\quad+j\beta_qa'\frac{3m}{2}[1+3b^2]\frac{du_1}{dz}\\&\quad-9\beta_q{}^2\frac{m}{2}[a'^2(1+b'^2)+b'^2]u_1\\&\quad-9a'^2b'^2\beta_q{}^2\frac{m^2}{4}u_1{}^*=0.\end{aligned}\tag{6}$$

The asterisk indicates the complex conjugate of a quantity and the assumption $(a'\omega_q/\omega)\ll1$ has been made. Eqs. (5) and (6) can be integrated by standard linear methods using the operator $d/dz=\beta_q\mu$. There will be eight waves propagating in this system. An approximate solution for the case of a thin beam $(a'=b'=1)$ and for small pump amplitudes, $|m|<1$, is given as

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* Received by the IRE, January 7, 1960.

[1] W. H. Louisell and C. F. Quate, "Parametric amplification of space-charge waves," PROC. IRE, vol. 46, pp. 707–716; April, 1958.

[2] H. A. Haus, "The kinetic power theorem for parametric longitudinal beam amplifiers," IRE TRANS. ON ELECTRON DEVICES, vol. ED-5, pp. 225–232; October, 1958.

[3] A. Ashkin, T. J. Bridges, W. H. Louisell, and C. F. Quate, "Parametric electron beam amplifiers," 1958 WESCON CONVENTION RECORD, pt. 3, pp. 13–22.

$$\mu_{1,2} \approx \pm j6.0$$
$$\mu_{3,4} \approx \pm j2.0$$
$$\mu_{5,6} = 0.375\,|m| \pm j1.25\,|m|$$
$$\mu_{7,8} \approx -0.375\,|m| \pm j1.25\,|m|. \qquad (7)$$

More exact values of the propagation constants are shown in Figs. 1 and 2 respectively for a thin beam and a beam of finite thickness. The wave amplitudes can be calculated by using the boundary conditions that the signal is initially excited in the beam as a pure single space-charge wave and that the initial upper sideband velocity is zero. It can then be shown that only the growing or declining waves are appreciably excited. Gain can be obtained by adjusting the pump phase to $\Phi=\pi/2$. The velocity wave amplitudes for a thin beam are then described as

$$u_{\mathrm{I}} \approx 1.05 \cos\left(1.25\,|m|\,\beta_q z - 17.84^\circ\right)$$
$$\exp 0.375\,|m|\,\beta_q z \exp -j\beta_e z\left(1-\frac{a'\omega_q}{\omega}\right) \qquad (8)$$

$$u_{\mathrm{II}} \approx 1.822 \sin\left(1.25\,|m|\,\beta_q z\right) \exp 0.375\,|m|\,\beta_q z$$
$$\exp -3j\beta_e z\left(1-\frac{a'\omega_q}{\omega}\right). \qquad (9)$$

It can be concluded that the upper sideband is heavily excited in the beam. The growth constant is one half that obtained by Louisell and Quate;[1] therefore, the theoretical gain will be much lower than theirs and hence closer to the experimental value. The next refinement in the analysis would be the inclusion of the sidebands around the second harmonic of the pump. It is expected that this will provide still better agreement between theory and experiment, since the growth rate will be further reduced.

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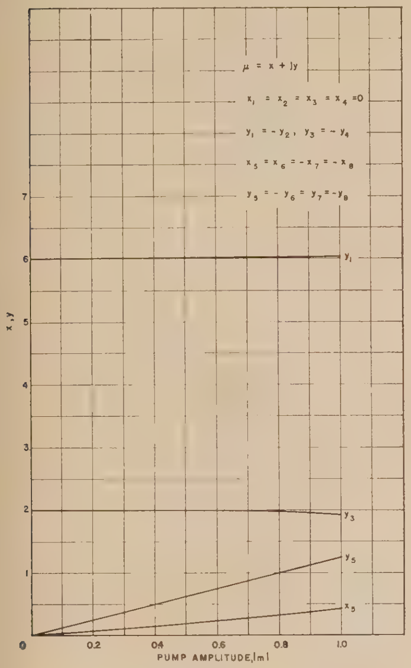

Fig. 1—Longitudinal-beam parametric-amplifier propagation constants as functions of pump amplitude $a'=b'=1$.

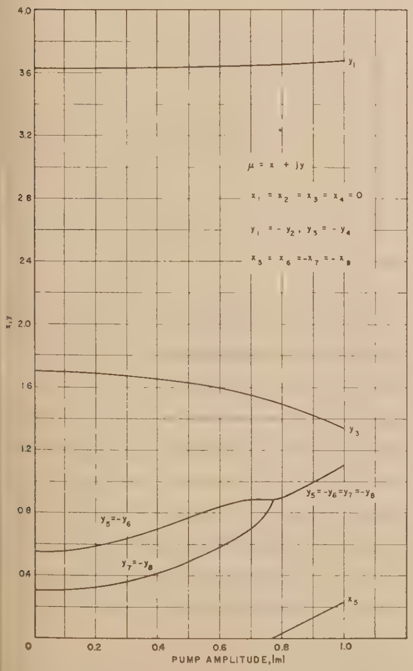

Fig. 2—Longitudinal-beam parametric-amplifier propagation constants as functions of pump amplitude $a'=0.697$, $b'=0.513$.

WWV Standard Frequency Transmissions*

The frequencies of the National Bureau of Standards radio stations WWV and WWVH are kept in agreement with respect to each other and have been maintained as constant as possible with respect to an improved United States Frequency Standard (USFS) since December 1, 1957.

The nominal broadcast frequencies should, for the purpose of highly accurate scientific measurements, or of establishing high uniformity among frequencies, or for removing unavoidable variations in the broadcast frequencies, be corrected to the value of the USFS, as indicated in the table below.

The characteristics of the USFS, and its relation to time scales such as ET and UT2, have been described in a previous issue,[1] to which the reader is referred for a complete discussion.

The WWV and WWVH time signals are also kept in agreement with each other. In addition, they are locked to the nominal frequency of the transmissions and consequently may depart continuously from UT2. Corrections are determined and published by the U. S. Naval Observatory. The broadcast signals are maintained in close agreement with UT2 by properly offsetting the broadcast frequency from the USFS at the beginning of each year when necessary. This new system was begun on January 1, 1960. The last time adjustment was a retardation adjustment of 0.02 seconds on December 16, 1959.

WWV FREQUENCY
WITH RESPECT TO U. S. FREQUENCY STANDARD

1960 January 1600 UT	Parts in 10^{10}†
1	−149
2	−149
3	−149
4	−149
5	−148
6	−148
7	−148
8	−148
9	−148
10	−148
11	−148
12	−148
13	−148
14	−147
15	−147
16	−146
17	−146
18	−145
19	−145
20	−145
21	−145
22	−145
23	−145
24	−145
25	−145
26	−145
27	−145
28	−145
29	−145
30	−145
31	−145

† A minus sign indicates that the broadcast frequency was low.

NATIONAL BUREAU OF STANDARDS
Boulder, Colo.

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* Received by the IRE, February 23, 1960.

[1] "United States national standards of time and frequency," PROC. IRE, vol. 48, pp. 105–106; January, 1960.

Tunnel Diode as an Interstage Gain Device*

The purpose of this letter is to demonstrate the applicability of the tunnel diode as an interstage coupling element with gain. It can be used in a transistor amplifier consisting of a cascade of "common-base" stages to provide impedance transformation and power gain between each stage. Fig. 1 illustrates the configuration used to obtain this impedance transformation and power gain. The gain equations are as follows:

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* Received by the IRE, December 17, 1959.

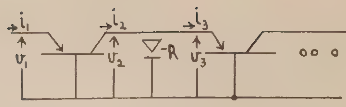

Fig. 1—Circuit configuration for tunnel diode interstage coupling, where $u_2=u_3$, and for $\infty_6=1$, $i_1=i_2$ (valid assumption for most transistors).

$$G_T=\frac{P_2}{P_1}=\frac{v_2i_2}{v_1i_1}=\frac{(-R)}{R_{\text{in}}+(-R)}$$

$$G_D=\frac{P_3}{P_2}=\frac{v_3i_3}{v_2i_2}=\frac{(-R)}{R_{\text{in}}+(-R)}$$

$$G_S=\frac{P_3}{P_1}=\frac{v_3i_3}{v_1i_1}=G_TG_D=\left[\frac{(-R)}{R_{\text{in}}+(-R)}\right]^2$$

$$\text{for stable gain } |R_{\text{in}}| < |-R|$$

$(-R)$ = negative resistance of tunnel diode
R_{in} = input resistance of common base transistor
G_t = transistor power gain
G_d = power gain per diode (interstage gain)
G_s = power gain per stage.

Since presently available diodes have negative resistance values of -40 to -200 ohms and since R_{in} for typical transistors can be controlled in this range, it is fairly simple to obtain the gain and stability desired.

A three stage IF amplifier using this coupling technique was designed and breadboarded. An over-all gain of 60 db was obtained for a bandwidth of 300 kc centered at 10 mc. The gain per transistor and the gain per diode were equal to 10 db each. Experimental tunnel (Esaki) diodes from the Sony Company in Japan were used; these had a negative conductance of -0.02 mho and a shunt capacitance of 500 $\mu\mu$f when operated in the tunnel region. The large value of shunt capacitance (500 $\mu\mu$f) was the limiting factor in the determination of center frequency and bandwidth for the desired gain. However, tunnel diodes are now being manufactured which have shunt capacitances of 15 $\mu\mu$f with the expectation that this will be reduced further in the future.

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Recent Developments in Very Broad-band End-Fire Arrays*

The transmission line excited Yagi or "straight ladder" antenna, shown in Fig. 1, was developed at this laboratory in the spring of 1958. This antenna may be described as a conventional Yagi array in which the driving element has been replaced by a shunted passive element and the array excited by electromagnetic coupling to a twin-wire transmission line, the twin-wire line being developed from a coaxial line in the manner shown in Fig. 1. In Fig. 2 we show a sketch of an experimental model of a two-bay straight ladder. This antenna was ultimately built full scale for operation at VHF (Fig. 3). It had a 20-foot boom length, 50-ohm input impedance, and a minimum over-all gain of 10 db (above isotropic) in a bandwidth of ±10 per cent.

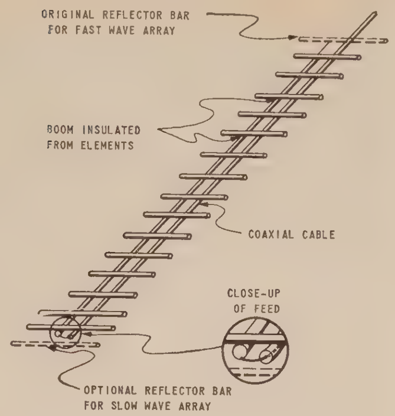
ORIGINAL REFLECTOR BAR FOR FAST WAVE ARRAY
BOOM INSULATED FROM ELEMENTS
COAXIAL CABLE
CLOSE-UP OF FEED
OPTIONAL REFLECTOR BAR FOR SLOW WAVE ARRAY

Fig. 1—Sketch of a straight ladder antenna.

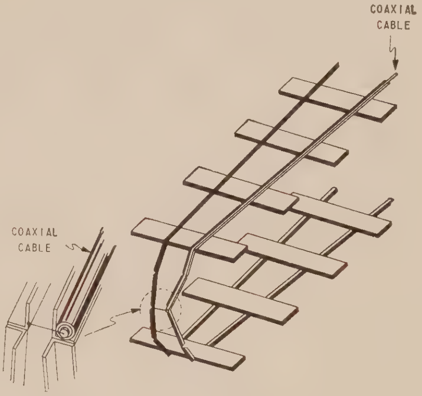

Fig. 2—Two-bay straight ladder antenna.

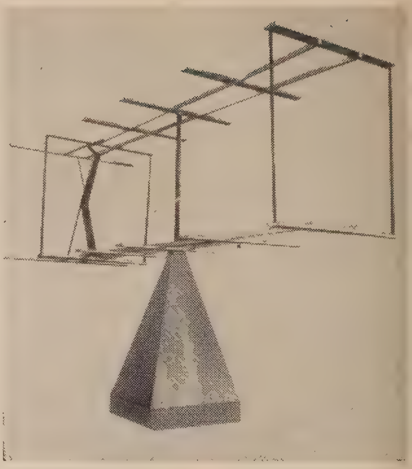

Fig. 3—Photograph of a two-bay VHF straight ladder antenna.

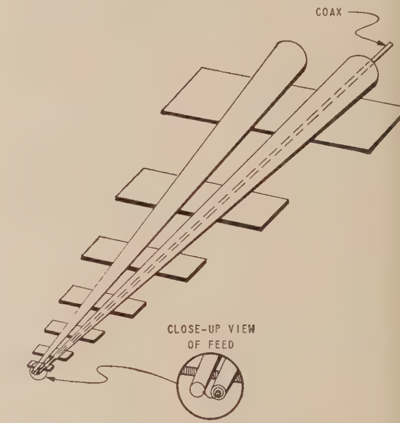

Fig. 4—Sketch of an early working model of a tapered ladder antenna.

It was subsequently realized that the ladder could be made indefinitely broad in bandwidth by using the principle employed by DuHamel and Isbell,[1] *i.e.*, by scaling the radiating elements in constant ratio. A sketch of one of our first working models of this antenna, called the "Tapered Ladder," is shown in Fig. 4. As in its predecessor, the straight ladder, the elements were electromagnetically coupled, *i.e.*, there were no conducting connections between the twin-line and the elements.

Typical *E*- and *H*-plane radiation patterns of a Tapered Ladder are shown in Fig. 5. These patterns were maintained over a bandwidth exceeding 4:1. The bandwidth can be increased simply by adding more elements. The antenna was excited from 50-ohm coaxial line, had a maximum VSWR of 2:1, and a measured gain of 8 db above isotropic.

In a later version of the Tapered Ladder we were able to match the antenna to 50 ohms with an average VSWR of 1.45:1 over a 7:1 frequency range. This was achieved by providing additional distributed loading for the twin-conductor transmission line. We have also built models with higher directivities, increase in directivity being derived from a reduction of the taper angle of the array. The taper angle is that angle subtended at the antenna vertex by each radiating element; thus, reduction of the taper angle amounts to reduction of percentage change in length of successive elements.

Other types of end-fire antennas can be made very broadband by tapering and exciting from twin-line, in particular the "Helix" and Cumming's "Zig-Zag."[2] A broadband "Tapered Zig-Zag" was developed by J. McDowell and the author. A sketch of such an antenna is shown in Fig. 6 and typical radiation patterns are shown in Fig. 7. The radiating structure of a Tapered Zig-Zag can be a slightly modified form of one-half of the V-shaped undirectional pseudo-infinite, logarithmically periodic

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* Received by the IRE, August 20, 1959.

[1] R. H. DuHamel and D. E. Isbell, "Broadband logarithmically periodic antenna structures," 1957 IRE National Convention Record, pp. 119–128.

[2] W. A. Cumming, "A nonresonant endfire array for VHF and UHF," IRE Trans. on Antennas and Propagation, vol. AP 3, pp. 52–58; April, 1955.

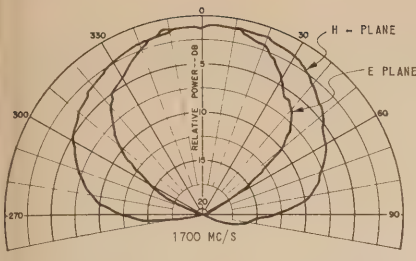

Fig. 5—Typical *E*- and *H*-plane radiation patterns of an early model tapered ladder antenna.

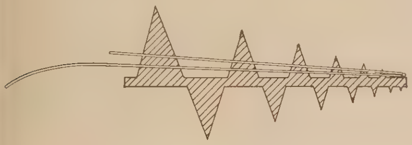

Fig. 6 Broadband tapered zig-zag.

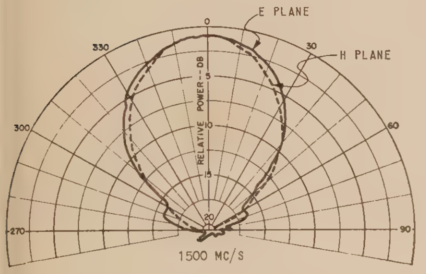

Fig. 7—Broadband tapered zig-zag radiation patterns, *E*- and *H*-planes at 1500 mc.

(PILP) antenna developed by Isbell.[3] In such case it is remarkable to note that the zig-zag structure has the same directivity as the original PILP.

We have found that the Tapered Ladder and the symmetrically excited Tapered Zig-Zag can be cut in half longitudinally and excited over a ground plane. Further, if the radiating elements are rotated 90° about their own longitudinal axes we have a transmutation to the broadband "Loaded Unipole" independently developed by Lamberty[4] at this laboratory.

The author and co-workers have made near-field amplitude measurements of the Tapered Ladder, and Franks and Bell[5] have made near-field phase and amplitude measurements of a PILP structure. In both cases we find that at any given frequency the antennas derive their directivity from an excitation length only half that of an equivalent Hansen-Woodyard array. Further, Franks and Bell find that the excess phase shift along the boom exceeds the 180° Hansen-Woodyard condition, the measured value being greater than 250°.

If we regard PILP structures, ladders, apex-fed helices[6] and spirals, line-fed zig-zags, etc. as loaded transmission lines, all of them appear to be generically related and resemble the "Comb" and "Fishbone" antennas developed several decades ago. With an analysis based on the loaded transmission line point of view, we have had fair success in predicting the radiation patterns of the Tapered Ladder. Relationships between excitation length, bandwidth, and directivity have been deduced from the uncertainty principle.

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[3] D. E. Isbell, "Non-planar logarithmically periodic antenna structures," Seventh Annual Symposium on the USAF Antenna Res. and Dev. Program, University of Illinois, Urbana; October 21–25, 1957.

[4] B. J. Lamberty, "A class of low gain broadband antennas," 1958 IRE WESCON Convention Record, pp. 251–259.

[5] R. Franks and R. Bell, Sylvania Electronic Defence Lab., Mountain View, Calif., private communication.

[6] H. S. Barsky, "Broadband conical helix antennas," 1959 IRE National Convention Record, pp. 138–146.

Nonreciprocal Radar Antennas*

We herewith report a successful extrapolation of the Dolph-Tchebycheff antenna concept with application to radar antennas or to any situation in which the system antenna pattern is the product of a transmitting antenna pattern and the pattern of a dimensionally-equivalent receiving antenna.

We begin by pointing out the inadequacy of the simple Dolph-Tchebycheff design in the radar case. In this design, the array factor for $(n+1)$ elements is forced by appropriate choice of feeding coefficients into a correspondence with T_n, where T_n denotes the Tchebycheff polynomial of degree n. Dolph[1] pointed out that the Tchebycheff correspondence produces the minimum beam angle for a given minor-lobe level. However, for the radar case in which the same antenna, or identical antennas, are used for transmission and reception, the system pattern (pattern and array factor are taken as equal) is $(T_n)^2$. $(T_n)^2$ is a polynomial of degree $2n$ but it is *not* equal to the Tchebycheff polynomial of the same degree (T_{2n}) and therefore the system pattern does *not* represent the optimum relationship between beam angle and minor-lobe level.

It is, however, quite simple to produce a system pattern with the desired Tchebycheff correspondence. Note first that T_{2n} is expressible in terms of T_n in the same way that the cosine of a double angle is expressible in terms of the cosine of the single angle. Thus

$$T_{2n} = 2(T_n)^2 - 1,$$

or

$$T_{2n} = 2\left(T_n - \frac{\sqrt{2}}{2}\right)\left(T_n + \frac{\sqrt{2}}{2}\right).$$

Therefore, if the excitation of the array center is adjusted to the different values between transmission and reception as implied by the above equation, the Tchebycheff correspondence for system pattern will have been realized.

This nonreciprocal action can be produced in a number of ways, perhaps the most simple of which is shown in Fig. 1. Here the power divider apportions the excitation of the array elements in accordance with $(T_n+\sqrt{2}/2)$. The isolator action is such as to leave this excitation unaltered for one direction of power flow and to introduce enough attenuation in the reverse direction to correspond to the $(T_n-\sqrt{2}/2)$ excitation.

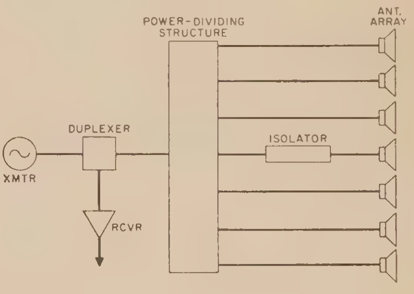

Fig. 1—Extended Tchebycheff nonreciprocal array.

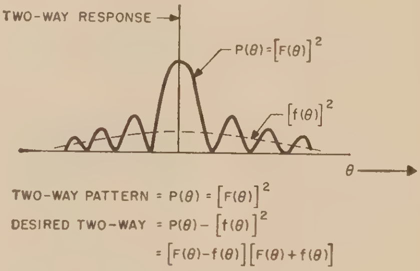
TWO-WAY RESPONSE
P(θ)=[F(θ)]²
[f(θ)]²
θ
TWO-WAY PATTERN = P(θ) = [F(θ)]²
DESIRED TWO-WAY = P(θ) − [f(θ)]²
= [F(θ)−f(θ)][F(θ)+f(θ)]

Fig. 2—Auxiliary radiator used to simultaneously sharpen beam angle and reduce sidelobes of two-way antenna pattern.

Using a given minor-lobe level as the basis of comparison, the extended Tchebycheff design will improve the beam angle by about 10 per cent over the conventional Tchebycheff design. For a given beam angle, the equivalent one-way minor-lobe improvement lies in the 4-to 5-db range.

This general principle has the simple continuous aperture analog illustrated in Fig. 2. Here the usual two-way pattern is shown as $[F(\theta)]^2$. The dotted $[f(\theta)^2]$ curve is selected to bisect exactly the largest minor lobe and may also approximately bisect several of the lesser minor lobes as well. If $[f(\theta)]^2$ could be made the angular axis (abscissa) then the minor-lobe level would be reduced by nearly 3 db and the beam angle slightly sharpened at the same time. It may be obvious by now that this effect can be produced by an auxiliary antenna whose one-way pattern is $f(\theta)$. This auxiliary antenna adds in phase to the principal lobe of the main antenna for transmission or reception, and adds in phase opposition to the principal lobe for reception or transmission. This action may be described by the algebraic relation:

$$[F(\theta)]^2 - [f(\theta)]^2 = [F(\theta) - f(\theta)][F(\theta) + f(\theta)].$$

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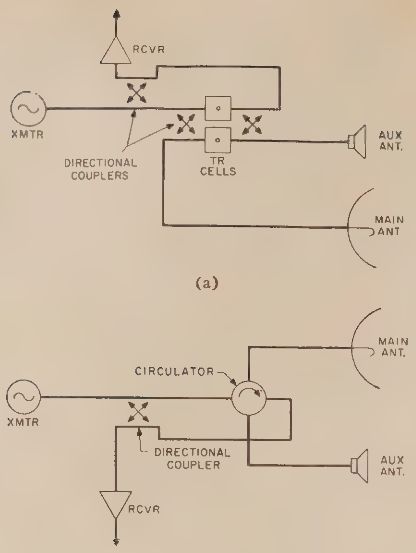
* Received by the IRE, August 20, 1959. The work reported herein was sponsored by the Ordnance Corps in connection with Contract DA-30-069-ORD-1955.

[1] C. L. Dolph, "A current distribution for broadside arrays which optimizes the relationship between beamwidth and sidelobe level," Proc. IRE, vol. 34, pp. 335–345; June, 1946.



(a)

(b)

Fig. 3—Mechanisms for addition and subtraction of auxiliary radiator.

Possible mechanisms for this alternate addition and subtraction are shown in Fig. 3.

The ideas described in the foregoing have been verified experimentally for both arrays and continuous apertures at these laboratories.

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Note on the Noise Figure of Negative Conductance Amplifiers*

The problem of coupling a negative conductance amplifier stage to another stage is sometimes solved by means of a circulator.[1] The purpose of this note is to discuss two solutions that do not require the use of a circulator. One solution consists of connecting the negative conductance amplifier stage directly to a receiver; the other solution connects the stage to a receiver by means of a lossless step-down transformer of suitably chosen turn ratio n.

Let the negative conductance amplifier stage consist of a negative conductance device of conductance $-g_d$ parallel to a signal source of conductance g_s, where $g_s > g_d$. The available gain of the stage is then (see Fig. 1):

$$G_{av} = g_s/(g_s - g_d), \tag{1}$$

and the amplifier stage is stable. Let the noise of the amplifier be represented by a source current generator i_s and a device current generator i_d and let

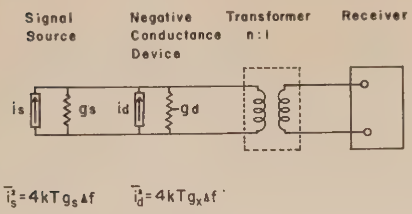
Signal Source
Negative Conductance Device
Transformer n:1
Receiver
is
gs
id
gd
$\overline{i_s^2} = 4kTg_s\Delta f$
$\overline{i_d^2} = 4kTg_x\Delta f$

Fig. 1.

$$\overline{i_s^2} = 4kTg_s\Delta f; \quad \overline{i_d^2} = 4kTg_x\Delta f. \tag{2}$$

The noise figure F_1 of the amplifier stage, neglecting losses, is then

$$F_1 = 1 + g_x/g_s. \tag{3}$$

Let the receiver have a noise figure $F_2(g_s')$ if a signal source of conductance g_s' is connected parallel to the input, and let F_2 have the minimum value $(F_2)_{\min}$ for $g_s' = (g_s')_{\min}$. If the negative conductance amplifier stage is connected directly to the input of the receiver, the receiver looks into a source conductance $g_s' = (g_s - g_d)$; if it is connected by means of a step-down transformer, the receiver looks into a source conductance $g_s' = n^2(g_s - g_d)$, if n is the turn ratio of the transformer. In either case $g_s' > 0$, since $g_s > g_d$.

Since the output conductance $(g_s - g_d)$ of the negative conductance amplifier stage is positive, Friis' formula holds. The total noise figure F of amplifier plus receiver is

$$F = F_1 + (F_2 - 1)/G_{av}. \tag{4}$$

We first consider the case in which the negative conductance amplifier is connected directly to the receiver and we assume that $g_s' = (g_s - g_d)$ is quite small. The asymptotic value of the noise figure is then

$$F = 1 + \left[g_x + \lim_{g_s' \to 0} g_s'\{F_2(g_s') - 1\}\right]/g_s, \tag{5}$$

as is found by substituting (1). Hence, the direct connection between the stage and the receiver does not give a significant increase in noise figure if

$$\lim_{g_s' \to 0} g_s'\{F_2(g_s') - 1\} \ll g_x. \tag{5a}$$

Next, we consider the case in which a step-down transformer of turn ratio n is used to connect the stage to the receiver. The minimum noise figure $F_{\min}$ is obtained if the source conductance $g_s' = n^2(g_s - g_d)$ is adjusted so that F_2 has its minimum value. Substituting (1), we obtain for $n^2(g_s - g_d) = (g_s')_{\min}$,

$$F = F_{\min} = 1 + [g_x + (g_s - g_d) \cdot \{(F_2)_{\min} - 1\}]/g_s. \tag{6}$$

Hence, the transformer connection between the stage does not give any significant increase in noise figure if

$$(g_s - g_d)\{(F_2)_{\min} - 1\} \ll g_x. \tag{6a}$$

It is always possible to write the noise figure of the receiver as

$$F_2 = 1 + A + R_{n0}g_s' + g_{n\infty}/g_s', \tag{7}$$

where A is usually a small factor, R_{n0} is the equivalent noise resistance for short-circuited input, and $g_{n\infty}$ is the equivalent noise conductance for open-circuited input; both quantities are easily measured. The noise figure has its minimum value

$$(F_2)_{\min} = 1 + A + 2\sqrt{R_{n0}g_{n\infty}}$$

$$\text{for } g_s' = (g_s')_{\min} = \sqrt{g_{n\infty}/R_{n0}}. \tag{7a}$$

Consequently (5) may be written

$$F = 1 + (g_x + g_{n\infty})/g_s, \tag{8}$$

and (5a) becomes

$$g_{n\infty} \ll g_x. \tag{8a}$$

Eq. (6) may be written

$$F_{\min} = 1 + \{g_x + (g_s - g_d)(A + 2\sqrt{R_{n0}g_{n\infty}})\}/g_s, \tag{9}$$

and (6a) becomes

$$(g_s - g_d)(A + 2\sqrt{R_{n0}g_{n\infty}}) \ll g_x. \tag{9a}$$

The above discussion is true for any type of negative resistance amplifier such as the parametric amplifier, the tunnel diode, etc. For the tunnel diode the dc current I_d shows full shot noise[2] so that

$$\overline{i_d^2} = 2eI_d\Delta f, \text{ or } g_x = (e/2kT)I_d. \tag{10}$$

In the case of the parametric amplifier, neglecting losses, the noise figure F_1 is[3]

$$F_1 = 1 + \frac{g_{ci}}{g_s}\frac{\omega_i}{\omega_0}, \tag{11}$$

where $-g_{ci}$ is the negative input conductance caused by the idler circuit, ω_i is the input frequency, and ω_0 is the idler frequency. Consequently,

$$g_x = g_{ci}\frac{\omega_i}{\omega_0}. \tag{11a}$$

The discussion has neglected to mention losses in the circuits, in the transformer, and, in the case of the parametric amplifier, the losses in the parametric device itself. It has also ignored the possibility of cooling some of the components, *e.g.*, the parametric device and the idler circuit in parametric amplifiers. It is not difficult to extend the discussion to include these effects.

A tunnel diode has a much lower impedance level than a parametric amplifier and as a consequence (5a) and (6a) and their equivalents are much more easily satisfied for the former than for the latter. Also, the influence of circuit losses will be less pronounced.

The authors are indebted to W. F. Leverton, Raytheon Manufacturing Company, Waltham, Mass., and R. L. Watters, General Electric Research Laboratory, Schenectady, N. Y., for discussion and correspondence.

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* Received by the IRE, September 18, 1959.

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[3] A. van der Ziel, "Noise figure of reactance converters and parametric amplifiers," *J. Appl. Phys.*, vol. 30; September, 1959.

Contributors

P. R. Arendt was born in 1900 in Dresden, Germany. He received the Ph.D. degree in physics from the University of Berlin, Germany in 1924. He studied under Plank, Einstein, Haber, and Hahn.

P. R. Arendt

From 1924 to 1929, he did research and development work for Siemens & Halske A.G., Berlin, on multiple carrier, picture telegraphy over loaded cables, and acoustical standards.

From 1929 to 1935, he was with International Telephone and Telegraph Corp. in London, Paris and Berlin. He was Chief Engineer of the Berlin associates of ITT and did engineering and research in all fields of communications, including magnetic sound recording, wired wireless, common frequency broadcasting.

From 1935 to 1957, he was associated with Allgemeine Electricitaets-Gesellschaft in Berlin and in Frankfurt, Germany. He was Technical Director concerned with the supervision of research and development activities and of patent policy of the concern including associated companies (Telefunken and Osram). He also acted as consultant to the President of the Board and during the war he inaugurated the production of an infrared proximity fuze for the V-2.

From 1957 to the present, he has been with the U. S. Army Signal Research and Development Laboratory, Fort Monmouth, N. J., Institute for Exploratory Research; he is Chairman of Radiation Effects Committee. He is especially interested in research on satellite radio propagation.

Dr. Arendt is a member of the American Nuclear Society, and of Deutsche Physikalische Gesellschaft; he is listed in Who is Who in Atoms, London, England.

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Rosario S. Badessa was born in Boston, Mass., on March 29, 1920. He received the B.S.E.E. degree from the Massachusetts Institute of Technology, Cambridge, in 1941.

R. S. Badessa

In 1941, he joined the Naval Research Laboratory, Washington, D. C., where he engaged in the development of precision frequency standards and later worked in the field of radar countermeasures. In 1948, he joined the staff of the Research Laboratory of Electronics, M.I.T., where he participated in the development of missile guidance and electronically scanned radar systems. He is now engaged in the development of advanced radar techniques.

⁂

Donald L. Birx (S'49–A'51–M'54) was born in Baltimore, Md., on November 30, 1924. He received the B.E.E. degree from The Johns Hopkins University, Baltimore, Md., in 1944. In 1945, he entered the U. S. Navy and was employed as an instructor in the Radio Materiel School, Washington, D. C. In 1946, he re-entered The Johns Hopkins University in the graduate school, and received the Dr. Eng. degree in electrical engineering in 1951.

D. L. Birx

Since 1951, he has been with the Franklin Institute in Philadelphia, Pa., where he is currently a senior staff engineer in the electronics branch of the laboratories. At present, he is working in the measurements field, being concerned primarily with the measurement of low-level RF powers and the utilization of natural radiation in the navigation of space vehicles. Prior to this work, he was engaged in a variety of projects which have included the statistical design of experiments for the analysis of optical and electrical systems, the synthesis of networks utilized in the design of RF noise filters, and the study of nonlinear aspects of rate gyroscopes.

Dr. Birx is a member of the American Physical Society, Tau Beta Pi, Sigma Xi, and the Scientific Research Society of America.

⁂

Robert L. Blanchard (S'55) was born in Montreal, Can., on May 8, 1919. He received the B.S. degree in engineering physics from McGill University, Montreal, in 1941 and the M.S. degree in applied physics from Harvard University, Cambridge, Mass., in 1948.

R. L. Blanchard

In 1941 and 1942, he was appointed Instructor in physics at McGill University, and in 1953 and 1954 he served as lecturer on microwave theory and technique in the Graduate School, Evening Division, at Northeastern University Boston, Mass. He was in charge of Communication Research and Development for the Canadian Army Signal Corps in 1945 and 1946, following which he joined Raytheon Manufacturing Company, Waltham, Mass., where he developed UHF communication equipment. He was a consultant on electronic development and design for several companies in the Boston area during 1948–1949. In 1949, he joined Trans-Sonics, Inc., Burlington, Mass. where his work has comprised general applied physics with application to measurement and control, electromagnetic theory, microwave systems, network theory, and filter design. He was leader of the team that developed the first successful trajectory scoring system for ammunition and missiles directed at airborne targets. He has held senior positions at Trans-Sonics, Inc., including Chief Research Engineer 1952–1957, Chief Engineer, Electronics Division 1957–1958, and is presently Vice-President and Director of New Product Research.

⁂

Frederick E. Bond (M'47–SM'55) was born on January 10, 1920, in Philadelphia, Pa. He received the B.S.E.E. degree from Drexel Institute of Technology, Philadelphia, in 1941, the M.S.E.E. degree from Rutgers University, New Brunswick, N. J., in 1950, and the D.E.E. degree from Polytechnic Institute of Brooklyn, N. Y., in 1956.

F. E. Bond

During World War II, he served with the U. S. Army Signal Corps in Europe, where his assignments included research and development on British fire control radar for coastal artillery, and staff planning for the use of electronic countermeasures. From May, 1946, to July, 1957, he was with the Communications Department of the U. S. Army Signal Engineering Laboratories at Fort Monmouth, N. J., engaged in research and development of ground radio and wire transmission equipments and communication systems engineering. His last position there was Director of the Radio Communications Division. At present he is a member of the senior staff of the Ramo Wooldridge Division of Thompson Ramo Wooldridge Incorporated.

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He joined the Boeing Airplane Co. in 1948 at Holloman Air Force Base, N. M., as a telemetry engineer for the duration of the GAPA Program. In 1950, he worked for Northrop as a radio control engineer on the SNARK Program. He joined Land-Air, Inc. at Holloman in 1951. He worked in the field of electronics trajectory and served on the IRIG for three years. He joined Lockheed Missiles and Space Division at Palo Alto, Calif., in 1959 in the field of instrumentation research.

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S. P. Brown

Samuel P. Brown (SM'59) was born on November 25, 1921, in Greensburg, Pa. He received the B.S. E.E. degree in 1942 from Pennsylvania State University, University Park, and the M.S.E.E. degree from Rutgers University, New Brunswick, N. J., in 1950. He received additional army electronics training at the General Electric Company, Schenectady, N. Y., taking courses in radio and radar techniques.

From January, 1943, to August, 1946, he was in military service, and was responsible for the system and field evaluation of newly developed microwave radio relay systems at the Signal Corps Ground Signal Agency. He is currently in the U. S. Army Reserve as a Major in the Signal Corps. His present title is Director, Astro-Electronics Division, Communications Department (supervisory electronic engineer) at the U. S. Army Signal Research and Development Laboratory, Fort Monmouth, N. J.

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Harry R. Buchanan (A'47–M'55) was born in Lawrence County, Ill., on March 26, 1921. He received the B.S. degree in engineering physics from the University of Illinois, Urbana, in 1943. After graduation, he entered the General Electric Company's Engineering Training Program for one year.

In 1944 he joined the Electronics Department of the General Electric Co., Schenectady, N. Y. From 1944 until 1955, he was engaged in the design and development of microwave components used in high power military and commercial radar systems. In 1955, he joined the engineering staff of the Jet Propulsion Laboratory, California Institute of Technology, Pasadena. At present, he is a member of the Electronics Research Section, engaged in microwave research activities relating to long-range space communications systems.

H. R. Buchanan

Mr. Buchanan is a member of RESA.

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C. R. Cahn

Charles R. Cahn (S'51–A'52–M'57) was born on October 7, 1929, in Syracuse, N. Y. He received the B. E. E. degree in 1949, the M. E. E. degree in 1951, and the Ph. D. degree in electrical engineering in 1955, all from Syracuse University, Syracuse, N. Y.

From 1949 to 1956, he served as instructor and later as assistant professor in the Electrical Engineering Department of Syracuse University, where he was engaged in research work in information theory and microwave antennas and in studies on systems engineering. From 1952 to 1953, on a leave of absence, he was employed in the System Planning Department of the Niagara Mohawk Power Corporation, Buffalo, N. Y., where he was concerned with system planning and econonic operation of a large integrated power system. At present, he is a member of the senior staff of Ramo-Woolridge, a division of Thompson Ramo Wooldridge, Inc., Los Angeles, Calif., where he is working on systems analysis and synthesis, with emphasis on applications of information theory in the field of digital communications. He has also investigated techniques for electronic countermeasures and methods of achieving reliable transmission over fluctuating circuits.

Dr. Cahn is a member of Sigma Xi and the AIEE.

◆

William O. Campbell (M'55) was born on August 26, 1920 in Natchez, Miss. He received the B.S.E.E. and M.S.E.E. degrees in 1948 and 1949, respectively, from the University of Tennessee, Knoxville.

From 1943 to 1946, he served with the U. S. Army Air Corps as a meteorologist. From 1949 to 1955, he was associated with Bendix-Friez in Baltimore, Md., where he was instrumental in the design of an automatic readout mercury barometer and an analog-digital computer for radiosonde data computation. Since 1955, he has been with The Martin Company, Baltimore, where, from 1955 to 1957, he was in charge of design groups for automatic checkout equipment for the Mace and Lacrosse Missiles. During 1957 and 1958, his position as staff Unit Head involved work on the Titan countdown equipment. Presently in the Space Flight Division, he is responsible for the electronic support equipment for space programs. He is currently enrolled in the graduate curriculum of Engineering Management at Drexel Institute of Technology, Philadelphia, Pa.

W. O. Campbell

Mr. Campbell is currently serving on the Test Equipment Committee of the Electronic Industries Association. He has recently filed a patent disclosure for digital checkout equipment.

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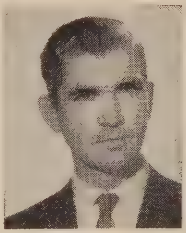

R. L. Choate

Robert L. Choate (S'50–A'52–M'57) was born on November 30, 1918, in Reevesville, Ill. He attended the University of Missouri School of Mines and Metallurgy, Rolla, where he received the B.S.E.E. degree in 1950 and the M.S. degree in physics in 1951.

From 1951 to 1953, he was employed by Bell Aircraft Corporation as electronics engineer in the development of missile guidance systems. In 1953, he returned to the Missouri School of Mines, where he served as instructor in physics and engaged in graduate studies in mathematics, physics, and electrical engineering. He has been employed at the Jet Propulsion Laboratory, California Institute of Technology, Pasadena, since 1955 as systems analyst in the Electronics Research Section. There he has been concerned with communication systems analysis, noise and filter theory, phase-locked-loop theory, secure communications, and deep space communications and tracking. He has participated in the Explorer series of satellite experiments and the lunar probe experiments (Pioneer III and IV).

Mr. Choate is a member of Sigma Xi and Sigma Pi Sigma.

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G. M. Clemence was born in Greenville, R. I., on August 16, 1908. He received the Ph.B. degree from Brown University, Providence, R. I., in 1930. He also received an Honorary D.Sc. degree from Case Institute of Technology, Cleveland, Ohio, in 1954.

He has been an astronomer at the U. S. Naval Observatory, Washington, D. C. since 1930. From 1945 to 1958, he was Director of the Nautical Almanac, and since 1958 he has been Scientific Director. He was a visiting professor of astronomy at Columbia University, New York, N. Y., in 1958, and has also written articles on positional astronomy, celestial mechanics time measurement, astronomical constants, mathematical tables, and navigation.

G. M. Clemence

Dr. Clemence is a member of the Senior Scientists Council of the Navy Department, the National Academy of Sciences, the American Academy of Arts and Sciences, the American Astronomical Society, the Bureau des Longitudes (France), the International Astronomical Union (of which he was President of the Commission on Celestial Mechanics from 1948 to 1955), and a foreign associate of the Royal Astronomical Society (England).

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R. T. Craig

Robert T. Craig was born on October 10, 1927, in Niagara Falls, N. Y. He received the B.S.E.E. degree from Massachusetts Institute of Technology, Cambridge, and the M.S.E.E. degree from Case Institute of Technology, Cleveland, Ohio. As a project engineer with the National Advisory Committee for Aeronautics from 1949 to 1955, he worked on the design and installation of controls and instrumentation for propulsion test facilities. He conducted research on control systems for gas turbine engines and wrote several NACA reports on gas turbine engine dynamic characteristics, control systems, and computer techniques.

He joined Thompson Ramo Wooldridge Inc., Cleveland, Ohio, in 1955 and directed design and development in advanced propulsion control systems and large-scale simulation studies. He has conducted system optimization and control analyses of nuclear power system and pneumatic controls, and has directed design of new analog computer components. He has directed trajectory and propulsion system analysis of electrically propelled vehicles, and has conducted research in high-temperature materials in the field of ion propulsion. He is now in charge of projects in propulsion system optimization, and experimental ion and plasma physics programs at the New Devices Laboratories, Thompson Ramo Wooldridge, Inc.

Mr. Craig is a member of AIEE, ARS, and Sigma Xi.

◆

W. Reed Crone (S'52–M'55) was born in Albert City, Iowa, on January 25, 1931. He attended the Milwaukee School of Engineering, Milwaukee, Wis., from 1948 to 1950, after which he served in the U. S. Navy as an electronic technician. In 1952, he was discharged to participate in the NROTC program at the University of Wisconsin, Madison, and received the B.S.E.E. and Bachelor of Naval Science degrees from that institution in 1955. He then re-entered the naval service and was assigned as Electrical Officer on an aircraft carrier until his release in 1958. Since that time, he has been pursuing graduate studies in electrical engineering and acting as research assistant at The Ohio State University Radio Observatory, Columbus, Ohio.

W. R. Crone

Mr. Crone is a member of Eta Kappa Nu and Tau Beta Pi and an associate member of the AIEE.

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A. F. Daniel

Arthur F. Daniel was born in Birmingham, Ala., on September 27, 1905. He received the B.S. degree in chemistry in 1927 and the M.S. degree in physics in 1928, both from the University of North Carolina, Chapel Hill. From 1928 to 1929 he attended the University of Chicago, Chicago, Ill., on a Charles A. Coffin fellowship in physics.

From 1929 to 1932, he was a research associate in electrical engineering at Harvard University, Cambridge, Mass. From 1933 to 1935, he was a research physicist with the General Chemical Co., Long Island, N. Y., and from 1935–1941, he was also a research chemist with the Storage Battery Division of T. A. Edison, Inc., West Orange, N. J. From 1941–1956, he was chemical engineer and Chief of the Battery Development Section of the U. S. Army Signal Research and Development Laboratory, Fort Monmouth, N. J. Presently he is a USASRDL general engineer and director of the Power Sources Division, Electronic Components Research Department, Fort Monmouth, where he is responsible for direction and coordination of research and design and development program to provide energy sources and energy conversion devices for use with U. S. Army Signal Corps equipment. In the field of primary batteries and special-purpose batteries, he is responsible for directing a research and development program for the Army and Air Force, and has received an Army exceptional civilian service award for battery research and development.

Mr. Daniel is a member of the American Chemical Society, the Electrochemical Society, the American Physical Society, the Armed Forces Communication Association, the Armed Forces Management Association, Sigma Xi, and Sigma Phi Sigma. He is listed in "American Men of Science."

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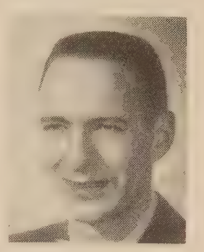
J. B. Day

John B. Day was born on March 3, 1928 in Erie, N. D. He served with the U. S. Navy as an airborne electronics technician from 1946 to 1951. In 1954, he received the B.A. degree in mathematics from San Jose State College, San Jose, Calif., and has studied graduate mathematics there and at Purdue University, Lafayette, Ind. After three years spent in teaching secondary mathematics in California and Indiana, he joined the Philco Western Development Laboratories, Palo Alto, Calif., in June, 1959. He is presently an engineer in the advanced applications section there.

Mr. Day is a member of Tau Delta Phi and Kappa Delta Pi.

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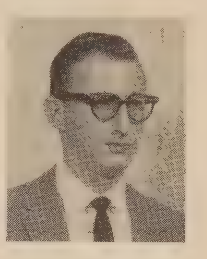
R. H. Dimond

Robert H. Dimond was born in Madison, Wis., on March 6, 1931. He received the, B.S.E.E. degree in 1955 from the Milwaukee School of Engineering, Milwaukee, Wis.

He joined Radiation, Inc., Orlando, Fla., in 1956 as an engineer in the Instrumentation Division. His work there has included contributions in atomic effects and complete environmental testing of airborne electronic systems; FM/FM, PPM/AM, PCM/FM telemetry systems; oscillographs; tape recorders; and associated instrumentation. He is currently with the Research Division of Radiation, Inc., which he joined in 1958 as a senior staff engineer. Included in his work there have been military technical intelligence evaluations and systems engineering in radio telemetry.

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E. F. Dirsa

Edward F. Dirsa (M'56) was born in Brighton, Mass. on October 20, 1925. He received the B.S. degree in physics from Boston College, Chestnut Hill, Mass. in 1950, and the M.S. degree in physics from Indiana University, Bloomington, in 1952.

From 1952 to 1954, he was engaged in magnetron tube development with Sylvania Electric Products, Inc., Boston, Mass. From 1954 to 1958, he was associated with Cook Research Laboratories, Morton Grove, Ill, where he worked on studies of electromagnetic propagation, design and analysis of countermeasures equipment and radar systems, and design of a unique radar target range for the Air Force. He is presently engaged in military systems engineering with the Admiral Corporation, Chicago, Ill.

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R. L. EASTON

Roger L. Easton (M'46) was born in Craftsbury, Vt., on April 30, 1921, and received the B.A. degree in physics from Middlebury College, Vt., in 1943.

Since that time he has been at the U. S. Naval Research Laboratory, Washington, D. C. He has worked on radar beacons, IFF, and on rocket and satellite tracking equipment. He worked on the design of the Minitrack system and had design responsibility for the 1958 Beta 2 (Vanguard I) satellite. He is now responsible for the detection portion of the Navy's dark satellite tracking program as head of the Space Surveillance Branch, NRL.

Mr. Easton is a member of the ARS.

◆

D. H. ELLIS

Donald H. Ellis (M'59) was born in Spartanburg, S. C., on March 8, 1927. He received the B.E.E. degree from Clemson College, Clemson, S. C., in 1951.

From 1944 to 1948 he served with the U. S. Navy. After graduating from college, he worked from 1951 to 1954 with the Atomic Energy Division of the E.I. du Pont deNemours Company on the control instrumentation of nuclear reactors. He then spent four years at the Massachusetts Institute of Technology's Lincoln Laboratory, Lexington, Mass., on the design and development of magnetic-core memory for digital computers. His prime responsibility was the development of a 256×256 coincident current magnetic-core memory for use in a large-scale digital computer, but he was also associated with the development of a high-speed transistorized core memory for use in a solid-state digital computer. At present, he is the Systems Development Unit Head involved in the design and development of airborne PCM data acquisition systems at Radiation, Inc., Melbourne, Fla.

Mr. Ellis is a member of Tau Beta Pi.

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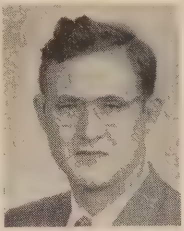

C. W. FETHEROFF

Charles W. Fetheroff was born on April 9, 1930, in East Cleveland, Ohio. He received the B.S.E.E. degree from Case Institute of Technology, Cleveland, Ohio, and has taken advanced work in servomechanisms, mathematics, circuit analysis, electronic circuits, electromagnetic theory, and atomic physics. He served in the U. S. Army Signal Corps from 1953 to 1955, doing research and development work on integrated radar defense systems.

Since joining Thompson Ramo Wooldridge, Cleveland, Ohio, in 1952, he has been responsible for electronic and magnetic component design, system stability studies for parallel alternators, design and development of auxiliary power unit simulators, and parametric analysis and startup stability studies on the Tartar and Terrier APU speed controls. He has performed hot gas servo analyses and has done research and development on electronic and mechanical components for application in extremely high ambient temperatures. In the field of advanced space propulsion, he has performed analysis and comparison of capabilities of chemical and electric propulsion systems, and is now in charge of refined studies on performance comparison of these two systems.

Mr. Fetheroff is a member of AIEE, ARS, Tau Beta Pi, Sigma Xi, and Eta Kappa Nu.

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J. J. FLEMING

James J. Fleming (A'42–M'55) was born in Chicago, Ill., on February 26, 1917. He received the B.S. degree in physics at Northwestern University, Evanston, Ill., in 1938. In 1941, after three years of graduate study in physics and service as a research assistant at Northwestern, he joined the Radio Division of the U. S. Naval Research Laboratory, Washington, D. C. During World War II, he contributed to the development of plan position indication for search radars. He was also responsible for the operational evaluation of Navy anti-aircraft gun fire-control systems, for which he received the Meritorious Civilian Service Award.

Since 1945, he has been Head of the Operational Research Branch at the U. S. Naval Research Laboratory, first in Radio Division III and now in the Applications Research Division. In addition to the development of the NRL Electronic Digital Computer (NAREC), the program of the Branch has included, for Project Vanguard, the development of an automatic telemetered data reduction facility (ARRF), a radar-computer ground-controlled third-stage firing system, and the Vanguard Computing Center. Currently, the Branch is engaged in the data processing problem of the Space Surveillance program.

Mr. Fleming is a member of the American Physical Society, the Association for Computing Machinery, the Scientific Research Society of America, and Phi Beta Kappa.

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R. FRANKLIN

Rachel Franklin was born in Dudley, N. J., on March 27, 1897. She received the B.A. degree from Vassar College, Poughkeepsie, N. Y., in 1919, and the M.A. degree from the University of Pennsylvania, Philadelphia, in 1929.

Her main interests have been in the field of optics and in the design of optical instruments. From 1930 to 1942, she was associated with the Biochemical Research Foundation in Newark, Del., working on the effects of ultraviolet radiation on living tissues and protozoa, and on the absorption spectra of normal and cancerous tissues. During World War II, she was employed by the U. S. Army Signal Corps, Ft. Monmouth, N. J., as an engineer in the development and inspection branch. In 1946, she joined the staff of the Franklin Institute Laboratories, Philadelphia, Pa., as a research physicist. She has worked in that capacity on various projects involving optics, including ultraviolet and infrared absorption spectroscopic studies and the design of specialized instruments for this work.

Miss Franklin is a member of the Optical Society of America, Phi Beta Kappa, and the Scientific Research Society of America, Franklin Institute Branch.

◆

W. H. GUIER

William H. Guier was born on July 13, 1926, in Wichita, Kans. He received the B.S. degree in 1948, the M.S. degree in 1950 and the Ph.D. degree in theoretical physics in 1951, all from Northwestern University, Evanston, Ill.

He joined the Applied Physics Laboratory of The Johns Hopkins University, Silver Spring, Md., in 1951, and is now a principal staff member in the field of theoretical physics. He recently received the "Outstanding Young Scientist" award which is sponsored by the Maryland Academy of Science.

Dr. Guier is a member of Lambda Chi Alpha, the American Physical Society, and the Philosophical Society of Washington, D. C.

◆

William R. Haseltine was born in Chicago, Ill., on June 27, 1911. He received the B.S. and Ph.D. degrees in physics in 1934 and 1938, respectively, from the Massachusetts Institute of Technology, Cambridge, Mass. He was a teaching fellow at M.I.T. in 1935 and 1936, an assistant in mathematics at the University of Wisconsin, Madison, in 1936 and 1937, and a research fellow in physics and lecturer at the University of California, Berkeley, from 1938 to 1941. From 1941 to 1945, he was an officer in the U. S. Army Ordnance Department.

W. R. Haseltine

Since 1946, he has been a physicist, primarily in rocket ballistics, at the U. S. Naval Ordnance Test Station, China Lake, Calif.

◆

Robert C. Higgy (A'26–SM'45) was born in Columbus, Ohio, on December 7, 1901. He received the B.S.E.E. degree from The Ohio State University, Columbus, in 1925 and the Professional Electrical Engineering degree in 1937.

R. C. Higgy

Since 1925, he has been employed by The Ohio State University as Director of Broadcasting Stations, Associate Professor of Electrical Engineering, and since 1956 as Associate Director for Engineering for radio and television stations and Assistant Director of the Radio Observatory. Recently, his work has included teaching electrical engineering and research work related to ionization effects due to earth satellites. He is the author of a book on fundamental radio experiments and of articles on ground wave propagation.

Mr. Higgy is a member of Sigma Xi and a licensed Professional Engineer in Ohio.

◆

Donald C. Hock was born in North Tonawanda, N. Y., on April 18, 1929. He received the B.A. degree from the University of Buffalo, N. Y., in 1951, the M.S. degree from the A & M College of Texas, College Station, in 1952, and the Ph.D. degree in physics from Pennsylvania State University, University Park, in 1956.

D. C. Hock

He joined the Applied Physics Laboratory of The Johns Hopkins University, Baltimore, Md., in 1955 as a member of the Senior Staff, and since 1958, has been with the Research Division of Radiation Incorporated, Orlando, Fla.

Dr. Hock is a member of Sigma Pi Sigma, Phi Kappa Phi, Pi Mu Epsilon, and Sigma Xi.

Conrad H. Hoeppner (SM'47–F'58) was born on March 12, 1918, in Spooner, Wis. He received the B.S.E.E. degree in 1939 and the M.S.E.E. degree in 1940, both from the University of Wisconsin, Madison. He did graduate work at the Massachusetts Institute of Technology, Cambridge, and received the professional E.E. degree in 1947 from the University of Wisconsin.

C. H. Hoeppner

Thereafter, he was employed by the U. S. Naval Research Laboratories, Washington, D. C.; he was Director of the Electronics Laboratory, Glenn L. Martin, Co., Baltimore, Md.; Director of the Engineering Products Department, Raytheon Manufacturing Company, Waltham, Mass.; Vice President and Director of General Electronics Laboratory, Inc., Cambridge, Mass.; Manager of the Electronic Division, W. L. Maxson Corp., New York, N. Y.; and Manager of the Development Division, Stavid Engineering, Plainfield, N. J. He is presently Chief Scientist at Radiation, Inc., Melbourne, Fla.

Mr. Hoeppner is a member of Sigma Xi, Pi Mu Epsilon, Phi Kappa Phi, Phi Eta Sigma, Tau Beta Pi, and Eta Kappa Nu, and is a Fellow of Tau Beta Pi, and the Wisconsin Alumni Research Institute.

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Hyman Hurvitz (M'53) was born in Boston, Mass., on February 18, 1910. He received the B.E.E. degree from Northeastern University, Boston, in 1930, and the L.L.B. and M.P.L. (Master of Patent Law) degrees from Washington College of Law (now American University), Washington, D. C., in 1936 and 1937, respectively.

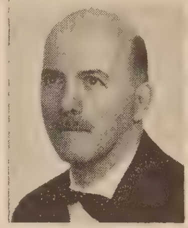
H. Hurvitz

He became a member of the Washington, D. C. Bar in 1937, and from 1942 to 1945, he served in the U. S. Navy, rising to the position of Lieutenant Commander. Since that time he has been in private practice, presently with the firm of Hurvitz and Rose, Washington, D. C.

◆

H. P. Hutchinson (A'32–SM'46) was born in Brooklyn, N. Y., in 1908. He received the B.S.E.E. degree from the Polytechnic Institute of Brooklyn, Brooklyn, N. Y., in 1930 and the M.S.E.E. degree from Columbia University, New York, N. Y., in 1933.

He has held numerous scientific and engineering positions, the most recent being Research Engineering, National Bureau of Standards; Chief Engineering, U. S. Army Aviation Center; and Assistant Director of Research, U. S. Army Signal Research and Development Laboratory, Ft. Monmouth, N. J. During World War II and in the Korean emergency, he served on military duty at the Pentagon directing Signal Corps' participation in nuclear weapons tests and in applied research.

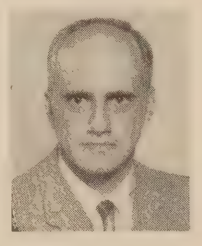

H. P. Hutchinson

Commencing with the first Sputnik, he has been continuously engaged in research on satellite signals and, together with P. R. Arendt, has written several papers on satellite radio propagation, His present position is Special Assistant to the Chief, Applied Physics Division, U. S. Army Signal Research and Development Laboratory.

Mr. Hutchinson is an Associate Member of Commission 3, USA National Committee of URSI.

◆

Donald J. Jacoby (M'46) was born in New York, N. Y., on July 8, 1920. He received the B.S.E.E. degree from Columbia University, New York, in 1941, and the M.S.E.E. degree from Rutgers University, New Brunswick, N. J., in 1950.


D. L. Jacoby

Since 1941, he has been employed at the U. S. Army Signal Research and Development Laboratory, Fort Monmouth, N. J., with the exception of three years as a radar officer in the U. S. Navy. He has been engaged in research and development programs in fields of multiplexing, radio relay and tropospheric scatter, and until recently was chief of the Radio Relay Branch of the Transmission Facilities Division. He is currently deputy director of the Astro-Electronics Division, USASRDL, with responsibility for directing programs in satellite communications, satellite instrumentation and tracking. He holds a patent on "Pulse Code Modulation."

◆

James R. Jenness, Jr. was born in Atlanta, Ga., on February 5, 1925. He received the B.S. degree in physics and mathematics from Parsons College, Fairfield, Iowa, in 1945 and the M.A. degree in physics from Temple University, Philadelphia, Pa., in 1954.

J. R. Jenness, Jr.

In 1945–1946, he taught mathematics in the high school at Birmingham, Iowa, was appointed to a graduate assistantship in physics at the

State University of Iowa, Iowa City, in 1946–1947, and in 1947–1948, was a senior fellow in physics at Iowa State College, Ames. From 1948 to 1951, he worked on special instrument calibration problems and the development of aeronautical research instruments for the NACA at Langley Field, Va. From 1951 to 1956, he was a physicist at the U. S. Naval Air Development Center, Johnsville, Pa., where his field of interest was infrared optics and guidance systems. Since 1956 he has been a Senior Physicist at HRB-Singer, Inc., State College, Pa., where he introduced the Hass-Erbe-Bradford replica mirror process for adaptation to large-scale production of low-cost precision reflective optical components by the Singer Military Products Division, and also developed techniques for fabricating paraboloidal microwave antennas by centrifugal casting. He has had a continuing interest in research instrumentation and the functioning of instruments and electronic components under unusual environmental conditions.

Mr. Jenness is a member of Phi Kappa Phi, Sigma Pi Sigma, Chi Beta Phi, the Optical Society of America, and the Association for Applied Solar Energy.

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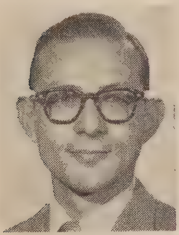
C. S. Josias

Conrad S. Josias (S'50,–A'51,–M'56) was born in New York, N. Y., on June 12, 1930. He received the B.E.E. degree from New York University, New York, in 1951 and the M.E.E. degree from the Polytechnic Institute of Brooklyn, N. Y., in 1955.

He was employed by Airborne Instruments Laboratory, Mineola, N. Y., from 1951 to 1956, during which time he was active in the development of electronic devices and systems. In 1956, he joined the Jet Propulsion Laboratory, California Institute of Technology, Pasadena, where he participated in the development of transistor circuits for missile guidance systems and space payload instrumentation. At present, he is a senior research engineer in the JPL Space Instruments Section.

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S. W. Kash

Sidney W. Kash was born on March 1, 1922, in New York City, N. Y. He received the Ph.D. degree in physics in 1951, from the University of California at Los Angeles.

During World War II, he worked at the Naval Ordnance Laboratory in Washington, D. C., on underwater degaussing problems. In 1947, he participated in a spectroscopic program related to the V2 firings at White Sands, N. M. In the early part of 1951, he designed equipment for the automatic measurement of skylight polarization for the Meteorology Department at UCLA. For the next four years, he was a senior engineer at Atomics International in Canoga Park, Calif., engaged in research and development of thermal neutron reactors. He has been with Lockheed Aircraft Corporation, Palo Alto., Calif., since the latter part of 1955, and is presently manager of the Ionic Physics Department. While at Lockheed, he has been engaged in a number of activities, including the design of high-pressure and electromagnetic shock tubes and research in plasma physics, hydromagnetics, and electrical propulsion.

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P. E. Kendall

P. E. Kendall (SM'56) was born in Paoli, Ind., on July 27, 1921. He received the B.S.E.E., M.S.E.E. and Ph.D. degrees from Purdue University, Lafayette, Ind., in 1948, 1949 and 1953, respectively.

He has taught undergraduate courses in electrical engineering at Purdue, and is an affiliate assistant professor at that university, teaching graduate courses in automatic controls and pulse circuitry. At ITT Laboratories, Fort Wayne, Ind., he has worked on system analysis and design of missile and space vehicle guidance and navigation systems; research in the field of nonlinear mechanics as applied to servomechanisms; optimization of contactor servos, and mercury drop noise generators in microwave frequencies; analysis of space vehicle trajectories; development of navigational equipments including Loran and radar altimeters; and operation and maintenance of military communications and radar equipments. He has held administrative positions as Head of the Electromechanical Section of the Advanced Development Department, Head of the Systems Analysis and Design Section of the Astrionics Laboratory, the position which he now holds.

Dr. Kendall is a member of Eta Kappa Nu and Sigma Xi. He has two patents pending.

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R. L. Kent

Robert L. Kent (M'59) was born in Philadelphia, Pa., on May 25, 1929. He attended the Moore School of Electrical Engineering, University of Pennsylvania, Philadelphia, where he received the B.S. degree in 1950, and the Massachusetts Institute of Technology, Cambridge, Mass., where he received the M.S. degree in 1952.

From 1950 to 1952, he was a research assistant in electrical engineering at M.I.T. Since that time, he has been a staff member of the Research Laboratory of Electronics, M.I.T., participating in the development of missile guidance and electronically scanned radar systems.

Mr. Kent is a member of Eta Kappa Nu, Sigma Tau, and Tau Beta Pi, and an associate of Sigma Xi.

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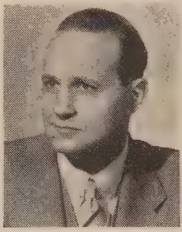
J. D. Kraus

John D. Kraus (A'32–M'43–SM'43–F'54) was born in Ann Arbor, Mich., on June 28, 1910. He received the B.S. degree in 1930, the M.S. degree in 1931, and the Ph.D. degree in 1933, all from the University of Michigan, Ann Arbor.

From 1934 to 1935, he did research on industrial noise-reduction problems and from 1936 to 1937, was engaged in nuclear research with the newly completed University of Michigan cyclotron. From 1938 to 1940, he was an antenna consultant. In 1940, he joined the Naval Ordnance Laboratory, Washington, D. C., working on the degaussing of ships, and in 1943, he became a member of the Radio Research Laboratory at Harvard University, Cambridge, Mass. In 1946, he joined the faculty of The Ohio State University, Columbus, where he is now professor of electrical engineering, professor of physics and astronomy, and Director of the Radio Observatory. He is responsible for the development of the helical beam antenna, the corner-reflector antenna, and other antenna types.

Dr. Kraus is a member of the American Astronomical Society and the American Physical Society.

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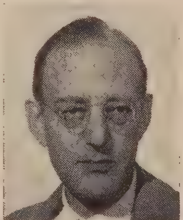
L. R. Malling

Leonard R. Malling (A'31–VA'39–M'59) was born in London, Eng., on July 9, 1909. He graduated from Northampton Technical Institute, London, Eng., in 1931 and came to this country in 1938.

For some 30 years, he has done research and design engineering in such areas as radar, nuclear resonance, aircraft guidance, guided missiles, and space vehicles. During this time, he has been employed by Hazeltine Electronics Corporation, Boeing Airplane Company, Convair, Varian Associates, and the U. S. Naval Laboratory, San Diego, Calif. In 1955 he joined the staff of the Jet Propulsion Laboratory, California Institute of Technology, Pasadena, where he is presently a senior research engineer.

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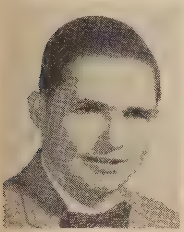
F. N. McMillan

F. N. McMillan was born on May 26, 1923, in Fayetteville, N. C. He received the B.S. degree with a group major in chemistry, mathematics and German from the University of Florida, Gainesville, in 1947 and the M.S. degree in chemistry from the same school in 1949.

From 1950 to 1955, he served as a chemist in the Florida Food and Drug Laboratory in Tallahassee. While in Tallahassee, he did additional graduate work in chemistry at Florida State University. From 1955 to 1958, he served as a research chemist at Eglin Air Force Base, Fla. Since 1958, he has been with the Research Division of Radiation Incorporated, Orlando, Fla. His work has included chemical kinetics, spectroscopy, immunology, organic synthesis, incendiaries, instrumentation, re-entry, and rocket propulsion.

Mr. McMillan is a member of Sigma Xi and the American Chemical Society.

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H. F. Meyer

Harold F. Meyer (SM'50) was born in New York, N. Y., on September 2, 1916. He attended Boston University, Boston, Mass., and Columbia University, New York, N. Y.

For many years he was active as a radio experimenter, amateur, member of the Naval Communication Reserve, and in the radio business. Entering Government service in the Signal Corps Plant Engineering agency in 1942, he became Chairman and Technical Secretary of the Technical Coordination Committee and Chief of the Engineering Coordination Section. In 1945, he transferred to the U. S. Army Research and Development Laboratories, Ft. Monmouth, N. J., and became Chief Engineer of the Long-Range Equipment Section. In 1955, he was made Chief of the Long-Range Radio Branch. In these capacities from 1946 to 1957, he was responsible for research and development of the Army long-distance radio communication equipment and systems. He joined the RamoWooldridge Division of Thompson Ramo Wooldridge Incorporated, Los Angeles, Calif., in 1957 as Co-Head of the Communications Systems Department and is currently employed in that capacity.

A. B. Moody

Captain Alton B Moody, USNR, was born in Thatcher, Ariz., on July 28, 1911. He graduated from the U. S. Naval Academy, Annapolis, Md., in 1935.

He has had experience in marine navigation in both the Navy and merchant marine, and in air navigation in both the Navy and Air Force. He has taught navigation in private schools and at the Naval Academy. He has been at the U. S. Navy Hydrographic Office since 1946, and for several years has been Deputy Director of the Navigational Science Division. In 1953 he received the international Thurlow Navigation Award for the outstanding contribution to the science of navigation.

Captain Moody is now President of the Institute of Navigation, a government member of the Governing Board of the U. S. Power Squadrons, a member of the Board of Governors of the American Polar Society, and a member of the New York Academy of Sciences and the Arctic Institute of North America.

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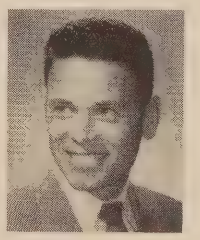
W. L. Morrison

William L. Morrison (A'52–M'59) was born in Salt Lake City, Utah, on April 3, 1924. After three years as an electronics technician in the U. S. Navy, he attended the University of California, Berkeley, and received the B.S.E.E. degree in 1953.

From 1953 to 1955 he was an electronic scientist at the U. S. Naval Radiological Defense Laboratory, San Francisco, Calif. From 1956 to 1958 he assisted in the design of the first nuclear reactor control console for the Atomic Energy Division of American-Standard, Inc., Mountain View, Calif. He is presently a senior research engineer in the Missiles and Space Division of Lockheed Aircraft Corporation, Palo Alto, Calif.

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G. E. Mueller

George E. Mueller (S'39–A'41–SM'46) was born on July 16, 1918, in St. Louis, Mo. He received the B.S.E.E. degree from the Missouri School of Mines, Rolla, in 1939. He continued his education at Purdue University, Lafayette, Ind., where he was a Research Fellow, and obtained the M.S.E.E. degree in 1940. He studied physics at Princeton University, Princeton, N. J., and received the Ph.D. degree in physics from The Ohio State University, Columbus, in 1951. He served as professor of electrical engineering at The Ohio State University for more than ten years.

His technical experience has included television and microwave research at Bell Telephone Laboratories, Holmdel, N. J., and work as a consultant for the Ramo-Wooldridge Corporation, Los Angeles, Calif. He is the author of nine technical publications, and holds six patents in the electron tube and antenna fields. He is presently Vice-President and Associate Director of the research and development division, Space Technology Laboratories, Inc., Los Angeles, Calif.

Dr. Mueller is a member of AIEE and the American Physical Society.

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H. L. Newkirk

Horace L. Newkirk was born in Minneapolis, Minn., on June 11, 1911. He received the B.S. degree from Union College, Schenectady, N. Y., in 1933 and the M.S. degree from the University of Idaho, Moscow, in 1940, both in physics. He has since taken additional courses in mathematical physics through the extension program of the University of California at Los Angeles.

From 1940 to 1945 he worked as a physicist in the Navy degaussing program. Since 1945, he has continued as a physicist with the Navy at the Naval Ordnance Test Station, China Lake, Calif., primarily in aeroballistics of rockets.

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G. C. Newton, Jr.

George C. Newton, Jr. (M'47) was born in Milwaukee, Wis., on May 14, 1919. He received the B.S.E.E. degree in 1941 and the D.Sc. degree in electrical engineering in 1950, both from the Massachusetts Institute of Technology, Cambridge. During World War II, he was engaged in defense research and development work at the Special Ordnance Plant in York, Pa., and at the Sperry Gyroscope Company, Inc., Long Island, N. Y.

He is presently Associate Professor of electrical engineering and Associate Director of the Electronic Systems Laboratory at M.I.T. In addition to teaching fundamental electrical engineering subjects and advanced courses in automatic control, he has research interests in the areas of instrumentation, control and computation. His consulting activities include services to both government and industry on military and commercial problems involving electronics and control technology

Dr. Newton is a member of the AIEE, the ASEE, and the Franklin Institute. He received Franklin Institute Levy Medal in 1953.

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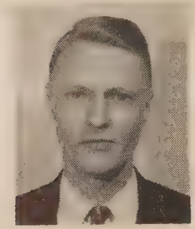
Robert R. Newton was born on July 7, 1918 in Chattanooga, Tenn. He attended the University of Tennessee, Knoxville, where he received the B.S.E.E. degree in 1940. He received the Ph.D. degree in theoretical physics from The Ohio State University, Columbus, in 1946.


R. R. Newton

For several years he taught in the Physics Departments of the University of Tennessee and Tulane University, New Orleans, La. During this time he also directed a research program in theoretical exterior ballistics for the Ordnance Missile Laboratories, Redstone Arsenal. He joined the Applied Physics Laboratory of The Johns Hopkins University, Silver Spring, Md., in August, 1957, and is now a principal staff member in the field of theoretical physics and supervisor of the Space Exploration Group.

Dr. Newton is a member of the American Physical Society, ARS, Sigma Xi, and Tau Beta Pi.

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William A. Nichols (M'57) was born in Spartanburg, S. C., on December 28, 1921. He served in the U. S. Marine Corps from January, 1940 to June, 1948 as radio-radar technician and instructor. He was an instructor in the U. S. Navy Electronics Technician Training Program from 1944 to 1947.

W. A. Nichols

He joined the U. S. Naval Research Laboratory, Washington, D. C., in November 1948. He has been responsible for the design and development of electronic instruments and telemetering facilities to implement rocket and satellite probes studying radiations of solar and other celestial bodies in the ultraviolet and X-ray regions. At present, he is Head of the Electrical Design and Engineering Section of the Upper Air Physics Branch.

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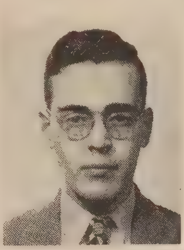
Joseph C. Nowell was born in Boston, Mass., on December 18, 1924. He received the B.S. degree in 1948, and the M.S. degree in 1950, both from Massachusetts Institute of Technology, Cambridge, Mass. He remained at M.I.T. to work on missile control systems in the Dynamic Analysis and Control Laboratory, and subsequently on missile guidance and advanced radar techniques in the Research Laboratory of Electronics. He is now with the Advanced Development Department of the Missile Systems Division, Raytheon Manufacturing Company, Bedford, Mass.


J. C. Nowell

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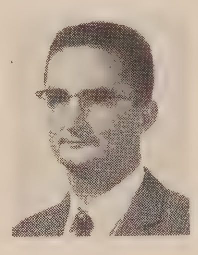
Douglas D. Ordahl was born on April 17, 1921, in Santa Rosa, Calif. He received the B.S. degree in chemistry from Stanford University, Stanford, Calif., in 1942, and the M.S. degree in chemical engineering from The Ohio State University, Columbus, in 1948.


D. D. Ordahl

He entered the propulsion field in 1942 at the Hercules Powder Company, Radford, Va., and in 1945 became a research engineer at Battelle Memorial Institute, Columbus, Ohio. In 1950, he joined the Naval Ordnance Test Station, China Lake, Calif., in order to continue research on the physical properties of solid propellants. He is presently Associate Head of the Propulsion Development Department there and does research, design, development and program direction of solid-, liquid-, ramjet-, and hybrid-propulsion systems.

Mr. Ordahl is a member of Phi Lambda Upsilon, ARS, and the American Chemical Society.

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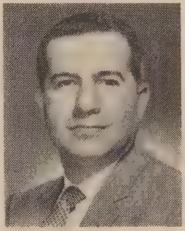
Merwin B. Pickover was born in New York, N. Y., October 8, 1929. He received the B.E.E. degree from the College of the City of New York in 1951.


M. B. Pickover

He was project engineer with the Bendix Corporation, Teterboro, N. J., and was transferred to the Red Bank division in 1952. His responsibility as project engineer was the design of missle and aircraft electrical accessories. In 1958, he joined the U. S. Army Signal Research and Development Laboratory, Fort Monmouth, N. J. As senior engineer, he now heads the team engaged in the design and development of tape recorder circuitry for satellite instrumentation; particularly, transistorized controls on recorder motors, for specialized applications as well as associating circuitry. At this time he is assigned to the Astro-Instrumentation Branch, Astro-Electronics Division, USASDRL.

◆

Norman S. Potter (SM'58) was born in New York, N. Y., on November 5, 1926. He received his undergraduate training at Brooklyn College, Brooklyn, N. Y., and at the U. S. Naval Academy, Annapolis, Md., where he studied marine and electrical engineering. He received the B.A. degree in mathematical physics from Brooklyn College in 1945 and the M.S. degree in applied mathematics and physics from Massachusetts Institute of Technology, Cambridge, in 1953. He continued supplementary studies at M.I.T. and Columbia University, New York, N. Y., for the Doctorate Degree.

N. S. Potter

As a member of the research staff, Columbia University, he was associated with the Manhattan Project, where he performed analytic studies in radiation propagation. Later a member of the research staff of the Department of Electrical Engineering at M.I.T., he worked for some years on SAGE system development, electron digital computer logic, data handling in real-time problems, advanced target acquisition techniques, and general air defense systems analyses. Following this, he was affiliated with The Martin Company for several years as a senior engineer in the field of advanced design, with primary responsibility for systems studies in several categories of missiles, airborne fire control systems, missile guidance techniques, and the analysis of composite airborne electronics subsystems.

He then served as a consultant at USAF Headquarters in Europe in the field of technical evaluation of foreign airborne weapons systems. Following his return from Europe, he was with the Air Arm Division of Westinghouse where, for several years as a Fellow Engineer and Weapons Systems Group Leader, he had primary responsibility for systems analyses and development in air-launched guided missiles, bomber detection and penetration techniques, airborne early warning and interceptor-borne detection and tracking equipments, advanced automatic acquisition techniques in discrete data systems, and operations analysis in large-scale air defense system evaluations.

For some years he has been engaged as a special consultant on guided missiles systems to the Assistant Chief of Staff, Intelligence, Department of the Army, and is presently manager of the Weapons Systems Research Laboratory of the Research and Development Division of the W. L. Maxson Corporation, New York, N. Y., where he is concerned with advanced systems studies in all phases of military and industrial electronics.

He is a member of the IAS, ARS, and AAAS.

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J. Praglin

Julius Praglin (M'56) was born in Boston, Mass., on June 12, 1927. He received the B.A. degree in biology from Clark University, Worcester, Mass., in 1948, and the M.S. and Ph.D. degrees in physiology from the University of Illinois, Urbana, in 1950 and 1952, respectively.

From 1952 to 1955, he was engaged in research on the biophysics of vision at Western Reserve University, Cleveland, Ohio. In 1955, he joined Keithley Instruments, Inc., Cleveland, Ohio, as director of Research and Development. He became a Vice-President of Keithley Instruments in 1957 and presently is in charge of Research and Engineering.

Dr. Praglin is a member of Sigma Xi.

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A. V. Pratt

A. V. Pratt was born in Maupin, Ore., on July 4, 1924. He received the B.A. degree from the University of California, Berkeley, in 1950 and has since done graduate work at the University of Utah, Salt Lake City, and the University of Colorado, Boulder.

He has worked for the U. S. Naval Ordnance Test Station, China Lake, Calif., since 1950 and is presently serving as a physicist in the Weapons Development Department there.

❖

A. G. Ratz

Alfred G. Ratz (M'49) was born in Hamilton, Can., on April 20, 1922. He received the B.A.Sc. degree in 1944, the M.A.Sc. degree in 1947, and the Ph.D. degree in 1951 from the University of Toronto, Can.

From 1947 to 1949, he was lecturer in electrical engineering at the University of Toronto. For the next three years, he was project engineer at the University's Computation Center where he did basic development work on digital computer techniques, culminating in the building of a digital computer. From 1952 to 1957, he was engaged in airborne electronic systems work at the Air Armament Engineering Department of Canadian Westinghouse. As a project engineer on air-to-air missile electronics, he was responsible for the development circuitry, subminiaturization, ruggedization, reliability and packaging of guidance systems. Subsequently, as section engineer and manager of the Systems Section, he directed a wide range of airborne projects, including guidance, control, aerodynamics, countermeasures, and planning and execution of missile flight tests and firings. In 1957, he joined the Applied Science Corporation of Princeton, Princeton Junction, N. J., where as assistant manager of the Engineer Planning Department he directed the study, research and development of pioneer telemetering hardware, including statistical telemetering devices. In January, 1959, he was appointed chief engineer. He joined Gulton Industries, Inc., in June, 1959, as Chief Engineer of the new Ortholog Division specializing in instrumentation, telemetry, and data-handling systems.

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H. B. Riblet

Henry B. Riblet (SM'44) was born on May 20, 1911, in Clayton, N. M. He graduated from Friends University, Wichita, Kans. in 1934 with a B.A. degree in physics and chemistry.

After graduation, he worked at radio station KLZ in Denver, Colo., as chief transmitter engineer. In 1940, he joined the consulting radio engineering firm of Glenn D. Gillett, Washington, D. C., where he was engaged in design and adjustment of directional antennas for radio broadcasting stations. During World War II, he was a member of the Research and Development Staff at Airborne Instruments Laboratory directed by Columbia University, New York, N. Y., where he was engaged in the development of airborne magnetic detection for submarines. After the war, he rejoined the Glenn D. Gillett firm. In March, 1949, he joined the staff of The Johns Hopkins University, Applied Physics Laboratory, Silver Spring, Md., to work with the Telemetering Group. In 1950, he was appointed Group Supervisor of the Telemetering Group, later known as Instrumentation Development. Recently, he has been the supervisor of an Electronics Group conducting development and engineering for satellite instrumentation.

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Robert W. Rochelle (S'46–A'50–M'58) was born on June 23, 1923, in Nashville, Tenn. He received the B.S.E.E. degree from the University of Tennessee, Knoxville, in June, 1947, and the Master of Engineering degree from Yale University, New Haven, Conn., in 1949. He began graduate studies at the University of Maryland, College Park, and taught in their graduate program for two years.

R. W. Rochelle

In March, 1949, he joined the Naval Research Laboratory, Washington, D. C., where he participated in the development of electronic instrumentation for the Pacific nuclear test. In 1956, he joined the Magnetic Amplifier Section, where he designed a telemetry system for the Vanguard satellite program. In November, 1958, he was transferred to the National Aeronautics and Space Administration and became head of the Flight Data Systems Branch, Payload Systems Division. He is currently working on electronic instrumentation for satellites and space probes.

Mr. Rochelle is a member of Tau Beta Pi, RESA, and AAAS.

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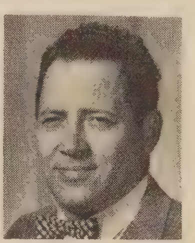

J. L. Ryerson

Joseph L. Ryerson (A'55–M'55) was born on October 20, 1918, in Goshen, New York. He received the B.E.E. degree from Thomas S. Clarkson College of Technology, Potsdam, N. Y., in 1941 and the M.A.E.E. degree from Syracuse University, Syracuse, N. Y.

Upon graduation he was employed as a development engineer by the Ward Leonard Electric Co. of Mt. Vernon, N. Y. In 1946, he was employed by the Associated College of Upper New York as a Professor of physics and later transferred to Evansville College, Evansville, Ind., as a Professor of physics and electrical engineering. Here, in addition to teaching, he became a registered professional engineer and entered the consulting field. Employed as an electronics engineer by the Rome Air Development Center, Rome, N. Y., in 1951, he was assigned the problem of investigating automatic landing. He is now the Senior Scientist, Office of Advanced studies, there.

Mr. Ryerson is a member of Sigma Phi Sigma.

❖

Charles Saltzer (M'56) was born on February 13, 1918, in Cleveland, Ohio. He studied mathematics and physics at Western Reserve University, Cleveland, Ohio, the University of Illinois, Urbana, the University of Nebraska, Lincoln, and Brown University, Providence, R. I. At Brown University he received the doctorate degree in applied mathematics in 1949.

He worked in gas dynamics at Brown University from 1943 to 1945 and was an instructor of mathematics from 1945 to

1948. He was appointed instructor of mathematics at Case Institute of Technology, Cleveland, in 1948 and subsequently to the positions of assistant professor and associate professor. He is on partial leave of absence and holds the position of Consulting Engineer at Thompson Ramo Wooldridge Inc., Cleveland. He was appointed professor of applied mathematics at the University of Cincinnati, Ohio, in 1960.

C. SALTZER

He was retained by the General Electric Company as a consultant in information theory and computer design from 1956 to 1958. He has also done consulting work in numerical analysis, biophysics and space technology, and has published papers on electrical network theory, switching theory, distributions and numerical analysis. He spent a year in England (1950–1951) on a Fulbright Exchange. He received a National Science Foundation Award for research on Finite Difference Operators in 1959.

Dr. Saltzer is a member of the American Mathematical Society, the American Mathematical Association, the London Mathematical Society, the Association for Computing Machines, the Society for Symbolic Logic, the ARS, and Sigma Xi.

* * *

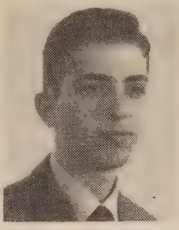
William F. Sampson was born in Oak Park, Ill., on July 6, 1929. He received the B.S. degree in physics from the California Institute of Technology, Pasadena, in 1951.

W. F. SAMPSON

He then joined the research staff of Jet Propulsion Laboratories at the California Institute of Technology. During his six years there, he took a leading part in the development and field testing of the Microlock Receiving System used in the Explorer satellite program. In 1957, he became head of the Space Communications section of Hallamore Electronics Company, in Anaheim, Calif. He directed the development of several subsystems for advanced telemetry systems; supervised the design, installation and check-out of tracking stations; and directed systems integration projects for space probe tracking and guidance complexes. He was then promoted to engineering manager, and directed research programs and corporate projects related to advanced systems. In November, 1959, he joined Space Technology Laboratories, Los Angeles, Calif., where he is a senior staff engineer in the Telecommunications Laboratory.

Mr. Sampson is a member of Tau Beta Pi and of Sigma Xi.

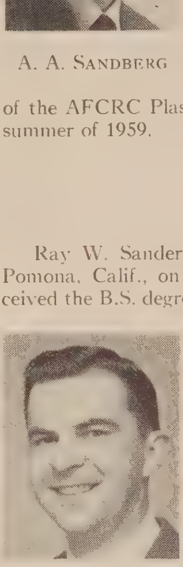
Allen A. Sandberg was born in New York, N. Y., on August 15, 1938. A senior at Massachusetts Institute of Technology, Cambridge, Mass., he expects to receive the B.S.E.E. and M.S. degrees in June, 1961.


A. A. SANDBERG

Through participation in the electrical engineering, cooperative program at M.I.T., he was a student member of the AFCRC Astrosurveillance Sciences Laboratory in 1958 and of the AFCRC Plasma Physics Unit in the summer of 1959.

* * *

Ray W. Sanders (SM'59) was born in Pomona, Calif., on April 24, 1927. He received the B.S. degree in physics and mathematics from Stanford University, Stanford, Calif., in 1948, and the M.S.E.E. degree from Stanford in 1950. From 1950 to 1951, he was an acting instructor and research assistant at Stanford.

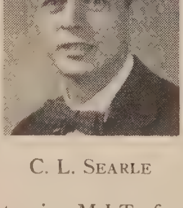

R. W. SANDERS

From 1951 to 1958, he worked at Gilfillan Bros., Inc., Los Angeles, Calif. in the fields of missile systems analysis and design, missile flight tests, air traffic control systems, automatic electronic countermeasure systems, and air navigation system analysis. While at Gilfillan, he served as Director of the Missile Section in the Engineering Department. He is presently with Space Electronics Corporation, Glendale, Calif., where he is Manager of the Space and Satellite Systems Department.

Mr. Sanders is a member of Sigma Xi and the American Ordnance Association.

* * *

Campbell L. Searle (S'46–A'48–M'55) was born in Winnipeg, Can., on July 24, 1926. He received the B.S.E.E. degree at Queens University, Kingston, Ontario, Can., in 1947, and the M.S. degree at the Massachusetts Institute of Technology, Cambridge, in 1951.

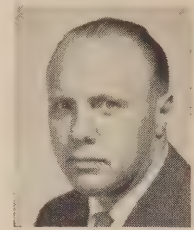

C. L. SEARLE

From 1948 to 1955, he was engaged in electronics research in the guided missile field at the Research Laboratory of Electronics, M.I.T., first as a research assistant and later, as a staff member of the Division of Sponsored Research. He joined the M.I.T. teaching staff in 1956, and is now an assistant professor in the Department of Electrical Engineering.

Mr. Searle is a member of Sigma Xi.

* * *

George F. Senn (SM'50) was born on May 11, 1913 in Philadelphia, Pa. He received the B.S.E.E. degree from Drexel Institute of Technology, Philadelphia, in 1935.


G. F. SENN

In 1935 he was with Philco Radio and Television Co. in Philadelphia and in 1936 with Radio Corporation of America in Camden, N. J. In 1937, he joined the U. S. Army Signal Research and Development Laboratory at Fort Monmouth, N. J., and since that time has been Chief of the Vehicular Installation Section, Chief of the Quality Control Division, and is currently the Chief Engineer of the Communications Department. In 1958, he was the project manager in charge of the "SCORE" Communications Satellite Project.

* * *

Arthur E. Sherburne (S'49–A'51–M'56) was born in Tyngsboro, Mass., on August 20, 1923. He received the B.S.E.E. degree from Tufts University, Medford, Mass., in 1950 and the M.S.E.E. degree from Massachusetts Institute of Technology, Cambridge, in 1951.

A. E. SHERBURNE

Since 1951, he has been employed at Trans-Sonics, Inc., Burlington, Mass., where he contributed to the development of airborne radar systems and in 1956 supervised the flight testing of a radar system. In 1958, he directed the development of an acoustic phase detector for Lox and JP-4. He has been a member of the New Product Research Department since its creation in 1958.

Mr. Sherburne is a member of Tau Beta Pi and Sigma Xi.

* * *

Frederick F. Slack was born in Lawrence, Mass., on June 16, 1917. From 1941 to 1945, he was engaged in research and development at M.I.T. Radiation Laboratory, Cambridge, Mass., and was granted several patents on radar indicator circuits. In 1945, he joined a newly formed organization which is now known as the Air Force Cambridge Research Center. As section chief in the Air Traffic Control Laboratory, he was responsible for the design and development of the first complete automatic track-while-scan unit for the VOLSCAN system. In connection with this work he invented the "light gun" for the acquisition of radar targets and assignment of automatic tracking gates. The light gun has since been adopted by a number of agencies for application in military radar systems, among them the SAGE system.

F. F. Slack

He is now chief of the Development Section of the AFCRC Astrosurveillance Sciences Laboratory, Bedford Mass. Dealing with special systems, he has developed the Cartesian coordinate automatic tracking system (CARTRAC) for the Tactical Air Command, designed a semiautomatic intercept computer (SAINT), and, more recently, evolved techniques for detecting the launching of missiles and satellites.

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Richard J. Slifka was born in Milwaukee, Wis., September 10, 1927. He received the B.S.E.E. degree from the University of Wisconsin, Madison, in 1951.

R. J. Slifka

After graduation, he joined the AC Spark Plug Division of the General Motors Corp., Milwaukee, Wis., as a service engineer. In this capacity, he was associated with the Gunsight and Bombing Navigational Computer projects. In 1956, he joined the AC Spark Plug Engineering Department, in which his projects included test planning and coordination of field sites for the inertial guidance equipment for the Thor Missile. He is now a senior project engineer, responsible for field operations for the inertial guidance equipment for the Thor Missile.

Mr. Slifka is a member of the AIEE.

❖

Alex G. Smith was born in Clarksburg, W. Va., on August 12, 1919. He received the B.S. degree in physics from the Massachusetts Institute of Technology, Cambridge, in 1943. During the remainder of the war, he worked at the M.I.T. Radiation Laboratory on magnetron development, and participated in the writing of a volume of the Radiation Laboratory Series. In 1948, he received the Ph.D degree in physics at Duke University, Durham, N. C., for which he wrote a dissertation on microwave spectroscopy.

A. G. Smith

Since that time he has been at the University of Florida in Gainesville, where he has held the ranks of assistant professor, associate professor, and, currently, full professor of physics. His research interests at the University have included microwave spectroscopy, military VHF electronics development, atmospheric optics, and low-frequency planetary radio astronomy.

Dr. Smith is a member of Sigma Xi, the American Physical Society, the American Optical Society, the American Astronomical Society, and the Astronomical Society of the Pacific.

❖

Robert T. Smith (M'56) was born in Kansas City, Mo., on October 25, 1930. He received the B.S.E.E. degree from the University of Kansas, Lawrence, in 1952, and while there he was employed by the University of Kansas Research Foundation on an analog computer development project.

R. T. Smith

Upon graduation, he joined the U. S. Naval Ordnance Test Station, China Lake, Calif., where he worked on air-to-ground fire control systems, special weapon fuzing systems, and automatic process control systems. In 1956, he assumed the responsibility of program manager for an airborne fire control program. He joined the Philco Western Development Laboratories, Palo Alto, Calif., in 1958, and is now manager of the advanced applications section of the satellite systems department. His current activities are in the analysis and design of current and proposed space electronic programs.

Mr. Smith is a member of Eta Kappa Nu and Sigma Tau.

❖

Roy C. Spencer (M'46–SM'50–F'60) was born on April 14, 1901 in Pennellville, New York. He received the B.A. degree from Cornell University, Ithaca, N. Y. in 1922, and the Ph.D. degree in physics from Columbia University, New York, N. Y., in 1932.

R. C. Spencer

From 1922–1923, he was a Fellow in Astronomy at Swarthmore, College, Swarthmore, Pa., and from 1923–1924, a Hechscher assistant in X rays at Cornell University. In 1926 and 1927, he was a Radio Tube Development engineer at the Westinghouse Lamp Co., Bloomfield, N. J. From 1927 to 1931, he was an instructor in physics at Columbia University, and from 1931 to 1941, he held positions of instructor, assistant professor and associate professor of physics at the University of Nebraska, Loncoln.

In 1941 he was granted a leave of absence from the University of Nebraska to become a staff member of the Radiation Laboratory of the Massachusetts Institute of Technology, Cambridge, Mass., where he carried out research on microwave antennas and diffraction theory. He was chief of the Antenna Laboratory of the Air Force Cambridge Research Center, Bedford, Mass., from 1946 to 1955, when he joined the Sylvania Missile Systems Laboratory, Waltham, Mass., as a senior engineering specialist and consultant. In 1958, he joined the Martin Company, Baltimore Division, Baltimore, Md., as principal staff scientist.

Dr. Spencer is a Fellow of the American Physical Society and the AAAS, and a member of the American Optical Society, the American Mathematical Society, Sigma Xi, and RESA (Research Society of America). He served on the U. S. National Committee of Commission VI of URSI and was a U. S. delegate to three International Assemblies in 1952, 1954, and 1957.

❖

James O. Spriggs (M'60) was born in Syracuse, N. Y., on May 18, 1914. He received the B.A. degree in sociology in 1936, the LL.B degree in 1940, and the B.A. degree in physics in 1945, all from Syracuse University, Syracuse, N. Y. He is a member of the New York State Bar.

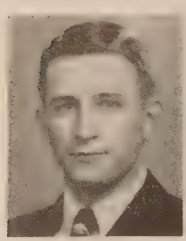
J. O. Spriggs

From 1940 to 1942, he practiced law with Spriggs, Merry, and Hartman of Syracuse. He was engaged in research and development in the fields of direction finding and countermeasures at the Naval Research Laboratory, Washington, D. C., from 1942 to 1949, receiving the Meritorious Civilian Service Award in 1946. From 1949 to 1958, he was in the Office of the Secretary of Defense, first in the Research and Development Board, the Office of the Assistant Secretary for Research and Development, and then the Office of the Director of Guided Missiles. Since 1958, he has been on the staff of the Advanced Research Projects Agency in the ballistic missile defense and space fields as Special Assistant to the Chief Scientist, to the Deputy Director, and, most recently, as Program Manager for the Courier communications and the Transit navigation satellite project.

❖

R. E. Stalcup was born in Bloomfield, Ind., on February 19, 1927. He received the B.S.E.E. and M.S.E.E. degrees from Purdue University, Lafayette, Ind., in 1950 and 1959, respectively. He is now working on the

Ph.D. degree at the University of Illinois, Urbana.


R. E. Stalcup

After receiving the B.S.E.E. degree, he joined ITT Laboratories, Fort Wayne, Ind., where he has done research and development in the following fields: design and development of magnetic amplifiers for servo applications and for computing devices; design of radio and television circuitry; design and development of digital computer circuitry, a radar system test set and fuze test set; Terrier and Bomarc missile programs; analysis, design and development of aircraft fire-control systems; studies pertaining to the use of radiometers in guidance systems; and analysis of infrared attitude control system for space vehicle (orbiting) and studies of applicability of Doppler radar to terminal guidance problems of space vehicles.

❖

A. R. Tanguay

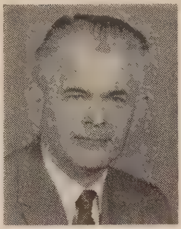
Armand R. Tanguay (S'49–A'51–SM'57) was born in Beloeil, Quebec, Can., on February 1, 1924. He received the B.S.E.E. degree from the University of Massachusetts, Amherst, in 1950 and the M.S.E.E. degree from the Massachusetts Institute of Technology, Cambridge, in 1951. While at M.I.T., he was a research assistant at the Digital Computer Laboratory (Project Whirlwind) doing research on electrostatic storage tubes.

From 1951 to 1957, he was employed at the Cornell Aeronautical Laboratory, Buffalo, N. Y. He was Associate Research Engineer from 1951 to 1955, concerned with research and development of military electronic systems and responsible for development of advanced missile ground guidance equipment. From 1955 to 1957, he was head of the Systems Analysis Section in the Weapons Systems Design Department, responsible for analysis, evaluation and data processing for the Lacrosse missile program, as well as for studies on advanced missile systems. Now with Radiation Incorporated, Orlando, Fla., he is Head of the Systems Research Department, with responsibility for advanced missile systems, space vehicle systems and guidance studies, computer simulation, and research in automation.

Mr. Tanguay is a member of Phi Kappa Phi and a senior member of the American Astronautical Society and Sigma Xi.

❖

Frederick J. Tischer (SM'55) was born on March 14, 1913, in Plan, Austria. He received the Ph.D. degree from the University of Prague, Czechoslovakia, in 1938, and did advanced study at the University of Berlin, Germany.


F. J. Tischer

Before coming to the United States in 1954, he directed activities in microwaves at the Royal Institute of Technology, Stockholm, Sweden. He headed a research group working on electronic guidance at Redstone Arsenal, Huntsville, Ala., until 1956, when he joined the staff of the Electrical Engineering Department, The Ohio State University, Columbus. He is now an associate professor, and has taught, among other courses, one on space communications for two years. He is the author of "Microwave Measurements," and of numerous articles on communication theory, microwaves, and electromagnetics. He is the inventor of the Ring Resonator, the H-Guide, and several other microwave devices and antennas.

Dr. Tischer is a member of Sigma Xi.

❖

T. H. Vea

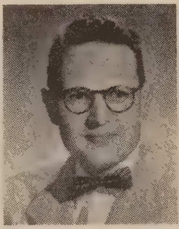
Theodore H. Vea (S'50–A'53–M'59) was born in Canton, Ohio on December 13, 1930. He received the B.S.E.E. degree from the University of Cincinnati, Cincinnati, Ohio, in 1953 where, on the cooperative engineering program, he was employed by the Wright Air Development Center in the search radar branch. In 1954–1955, he was an instructor in the electrical engineering department at the University of Pittsburgh, Pittsburgh, Pa., where he received the M.S. degree in 1955.

He has been employed by the Westinghouse Air Arm Division, Stanford Applied Electronics Laboratory, and the General Electric Computer Department where he has worked on airborne fire control systems, electronic countermeasure systems and the development of a data processing system for banking applications. In 1957, he returned to Stanford University to do graduate study and was a Research Assistant in the Radio Propagation Laboratory. In 1959, he joined the Philco Western Development Laboratory, Palo Alto, Calif., where he is employed as a project engineer in the advanced applications section of the satellite systems department. His activities include the analysis and design of communication systems for satellite applications.

Mr. Vea is a member of the American Institute of Physics, the Association for Computing Machinery, and AIEE.

❖

Joseph H. Vogelman (M'46–SM'49–F'59) was born in New York, N. Y., on August 18, 1920. He received the B.S. degree in 1940 from the College of the City of New York, N. Y., and the M.S. and Ph.D. degrees in 1948 and 1957, respectively, from the Polytechnic Institute of Brooklyn, N. Y., both in electrical engineering.


J. H. Vogelman

In 1945, after several years at the Signal Corps Radar Laboratory at Ft. Hancock and Belmar, N. J., he joined the staff of the Watson Laboratories, Red Bank, N. J., where he served as Chief of the Development Branch until 1951, responsible for research and development of test equipment and microwave components and techniques. In 1951, he moved to the Rome Air Development Center, Griffiss Air Force Base, Rome, N. Y. From 1951 to 1953, he was Chief Scientist in the General Engineering Laboratory and consultant on UHF and SHF theory and techniques to the Air Force. From 1953 to 1956, he was Chief of the Electronic Warfare Laboratory, directing all research and development in ground-based electronic warfare for the Air Force. From 1956 through June, 1959, he was Technical Director of the Communications Directorate with responsibility for the Air Force research and development effort in ground-based and ground-to-air communications. He is now Director of Research and Development at Dynamic Electronics Division, Capehart Corporation, Richmond Hill, N. Y.

Dr. Vogelman is a Fellow of the AAAS and a member of Eta Kappa Nu, Sigma Xi, the AIEE, and the Armed Forces Communications and Electronics Association.

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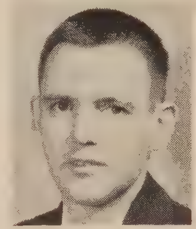

J. M. Walter, Jr.

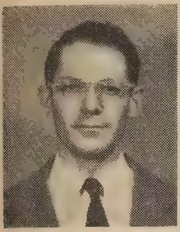
James M. Walter, Jr. (S'54–M'56) was born on March 13, 1931 in Harrodsburg, Ky. He received the B.E.E. degree from the University of Florida, Gainesville, in 1956.

After serving with the U. S. Navy for four years as an aviation electronic technician, he joined Radiation, Inc., Melbourne, Fla., in 1956. His work there has included participation in low-level electronic subcommutation, 250-channel multiplexer, RADICON, RADIAN, AFMTC Timing Terminal Equipment, PDM to digital coder and PPM to digital coder developments. He has recently been engaged in the development of a 96-channel digital data acquisition system for NORAIR and the acquisition system reported on in this issue.

Mr. Walter is a member of Sigma Tau and Phi Eta Sigma.

❖

George C. Weiffenbach was born on June 20, 1921 in Newark, N. J. He attended Harvard University, Cambridge, Mass. where h obtained the B.A. degree in 1949, and also Catholic University, Washington, D. C., where he obtained the Ph.D. degree in experimental physics in 1958.


G. C. Weiffenbach

He joined the Applied Physics Laboratory of The Johns Hopkins University, Silver Spring, Md., in 1951 and is now a senior staff member in the field of experimental physics.

Dr. Weiffenbach is a member of Sigma Chi, the American Institute of Physics, the American Geophysical Union and the Philosophical Society of Washington, D. C.

❖

William E. Williams, Jr. (SM'55) was born in Hattiesburg, Miss , on April 6, 1921. He received the B.S. degree in physics in 1942 from Mississippi State College.

After graduation, he joined the staff of the National Bureau of Standards where he was engaged in circuit design work on proximity fuzes for bombs and rockets. After a tour of duty in the Army from 1944 to 1946, he returned to the Electronic Instrumentation Section, NBS, where his field of work was in the design of a variety of special-purpose instruments to measure pressure, liquid levels, vibration, and oil film thickness, as well as pulse generators and temperature control equipment. From 1953 to 1956, he was engaged in the design of aircraft flight simulators with primary responsibility for the simulated radar and electronic countermeasures systems. From 1956 to 1959, he was responsible for the design of missile telemetry systems for the Diamond Ordnance Fuze Laboratory. Since then, he has been staff assistant for telemetry in the Office of Space Flight Operations, National Aeronautics and Space Administration.

W. E. Williams, Jr.

Mr. Williams is an associate member of the Telemetry Working Group of the Inter-Range Instrumentation Group.

L. Bruce Wilner was born in Fargo, N. D., on August 7, 1931. He attended Yale University, New Haven, Conn., with the assistance of scholarships, and received the B.E. degree in 1953. He studied at Stanford University, Stanford, Calif., and received an M.S. degree in mechanical engineering in 1954.

L. B. Wilner

He was employed by Los Alamos Scientific Laboratory for four years and participated in several weapons test operations. In 1958, he was employed by Lockheed Missiles and Space Division, Palo Alto, Calif., and is now working in the Instrumentation Research Group of the Communications and Controls Department at LMSD. His fields of activity have included nuclear component design, gas thermodynamics, and high-pressure technology, relaxation phenomena, and instrumentation for measurements in fluids.

Mr. Wilner is an associate member of ASME.

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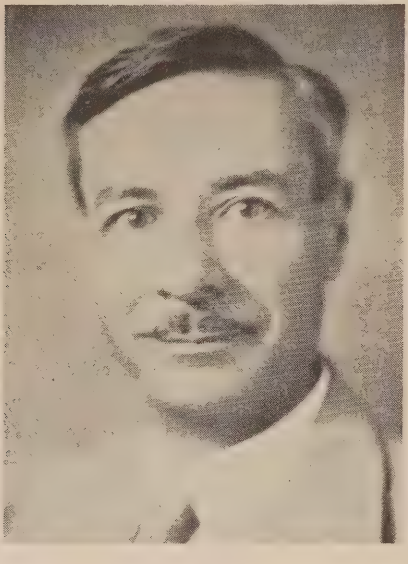
IRE Awards, 1960

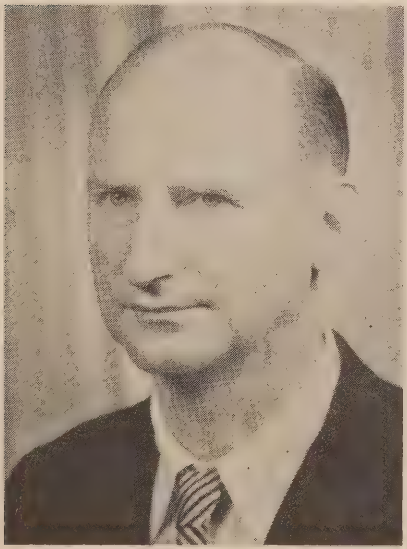
Founders Award



HARADEN PRATT

For outstanding contributions to The Institute of Radio Engineers through wise and courageous leadership in the planning and administration of technical developments which have greatly increased the impact of electronics on the public welfare.

Morris Liebmann Memorial Prize



J. A. RAJCHMAN

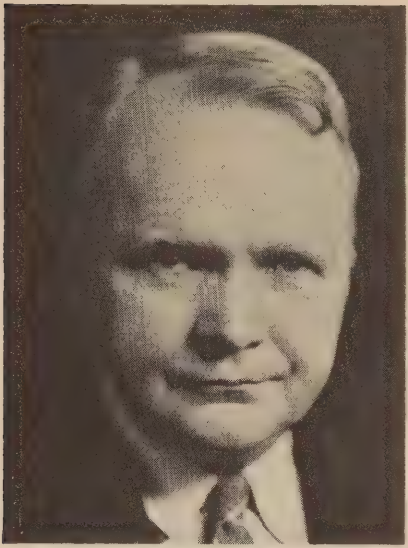
For contributions to the development of magnetic devices for information processing.

Browder J. Thompson Memorial Prize

J. W. GEWARTOWSKI

For his paper entitled "Velocity and Current Distributions in the Spent Beam of the Backward-Wave Oscillator," which appeared in the October, 1958 issue of the IRE TRANSACTIONS ON ELECTRON DEVICES.

Medal of Honor Award



HARRY NYQUIST

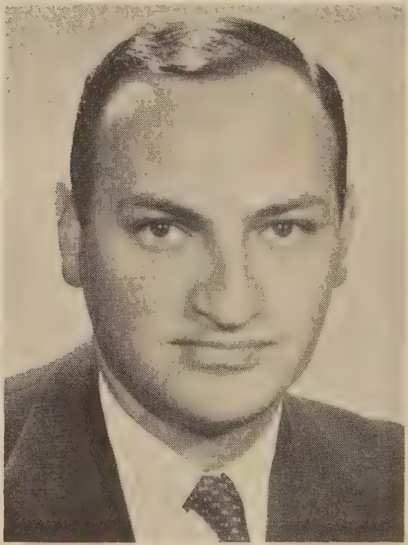
For fundamental contributions to a quantitative understanding of thermal noise, data transmission and negative feedback.

Harry Diamond Memorial Award

K. A. NORTON

For contributions to the understanding of radio wave propagation.

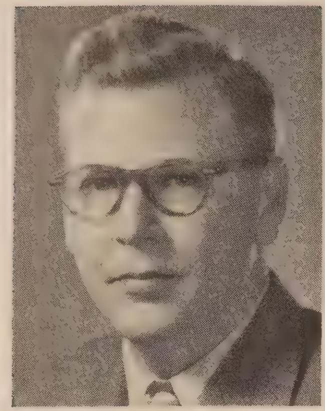
W. R. G. Baker Award



E. J. NALOS

For his paper entitled "A Hybrid Type Traveling-Wave Tube for High-Power Pulsed Amplification," which appeared in the July, 1958 issue of the IRE TRANSACTIONS ON ELECTRON DEVICES.

New Fellows



R. B. Adler

For contributions to engineering education and to research in electronics.

H. H. Aiken

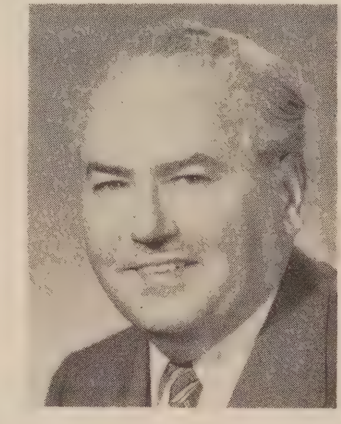
For contributions to the development of computer science and technology.

H. O. G. Alfven

For contributions to the understanding of the properties of plasmas.

W. M. Bailey

For contributions to capacitor technology.



Rudolf Bechmann

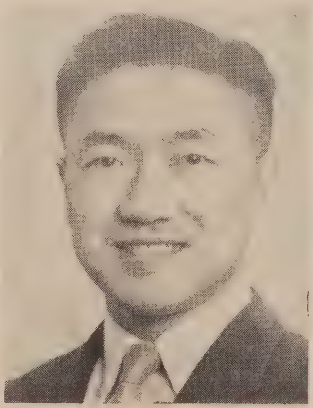
For contributions in the field of piezoelectric crystals.

J. I. Bohnert

For contributions in the field of micro wave antennas.

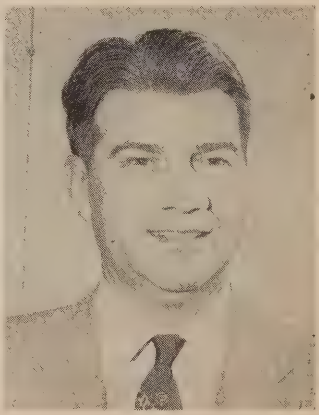
J. F. Calvert

For contributions to electrical engineering and education.



D. K. Cheng

For contributions to engineering education and antenna theory.



Trevor Clark

For contributions to military electronic

New Fellows

P. W. Crapuchettes

For contributions to microwave tube technology.

A. N. Curtiss

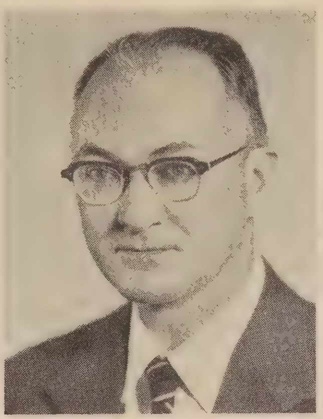
For contributions to radio and radar technology.

C. E. Dean

For contributions in the field of radio and television receivers.

G. A. Deschamps

For contributions to analysis of microwave components.



A. C. Dickieson

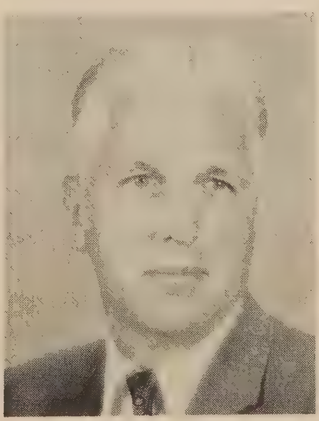
For contributions to wire and radio communications.

Stephen Doba, Jr.

For contributions in the field of television signal transmission.

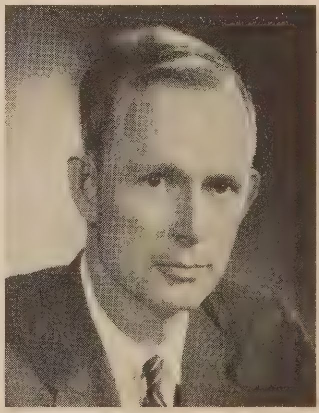
I. G. Easton

For contributions to impedance measuring techniques and equipment.



P. G. Edwards

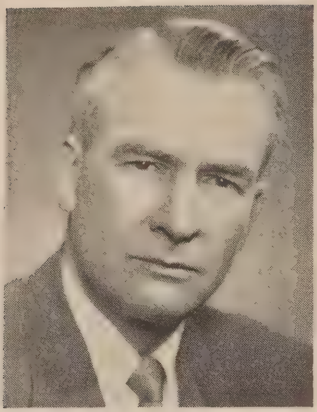
For contributions in the field of telephone communication systems.



J. H. Felker

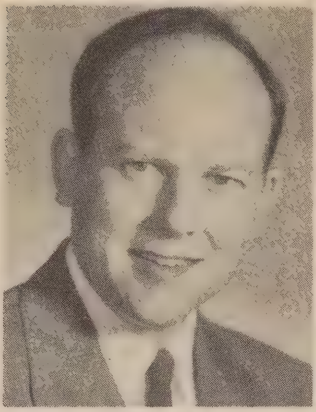
For contributions to computer technology.

New Fellows



G. J. Fiedler

For contributions to electronic process control systems.

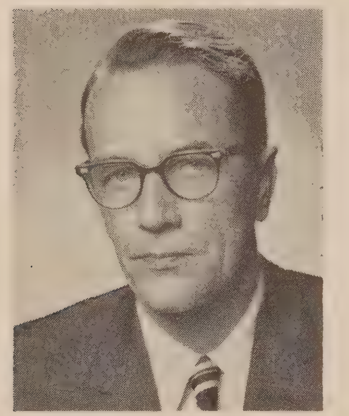


G. A. Fowler

For contributions to atomic energy instrumentation.

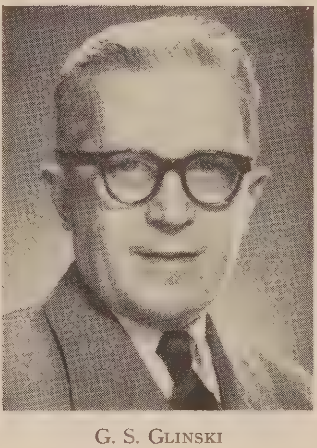
D. W. Fry

For contributions to research in controlled fusion.



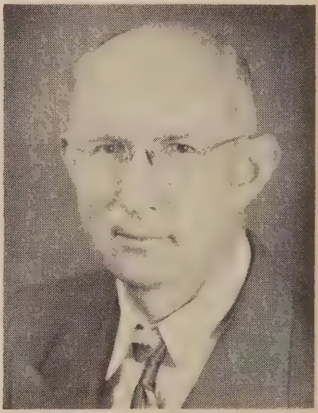
R. W. Gilbert

For application of electronics to measurement techniques.



G. S. Glinski

For contributions to the field of computation.

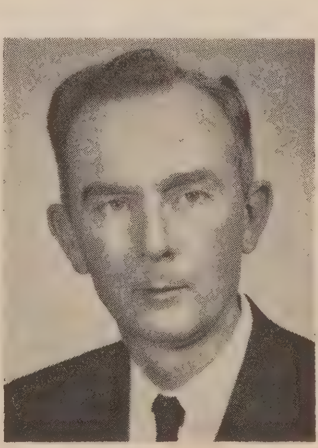


M. J. E. Golay

For contributions to the fields of com munications and infrared technology.

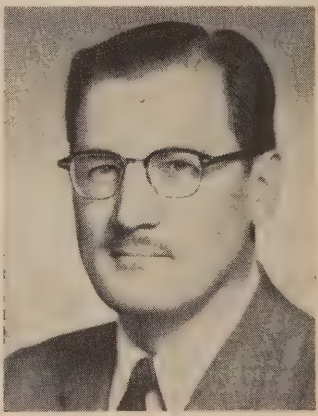
Georges Goudet

For contributions to engineering education and for the administration of research.



W. J. Hamm

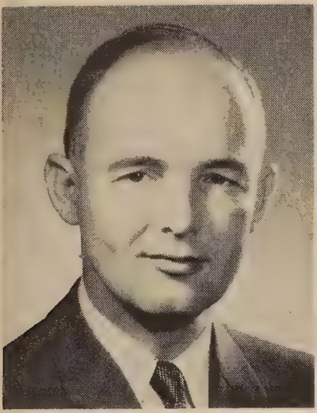
For service in teaching and research.



H. C. Hardy

For contributions to electroacoustics.

New Fellows

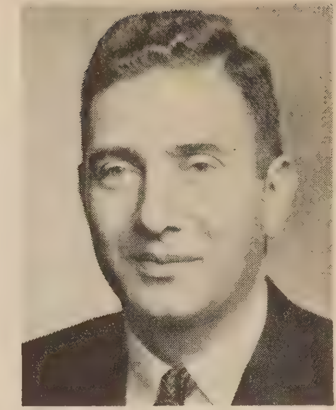


R. A. Helliwell

For contributions to ionospheric radio propagation.

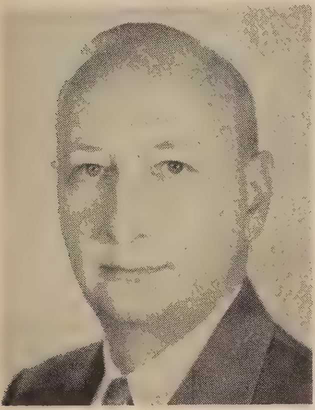
R. K. Hellmann

For work in military electronics.



S. W. Herwald

For contributions to servomechanism technology.



W. H. C. Higgins

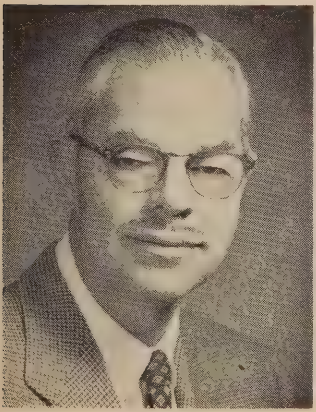
For contributions to military electronics.

C. L. Hogan

For pioneering in the application of ferrites.

J. M. Hollywood

For contributions to electronic countermeasures and color television.



F. L. Hopper

For contributions in underwater sound search and sound recordings

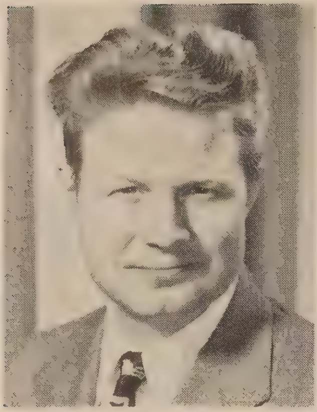
P. W. Howells

For contributions to color television.

H. R. Huntley

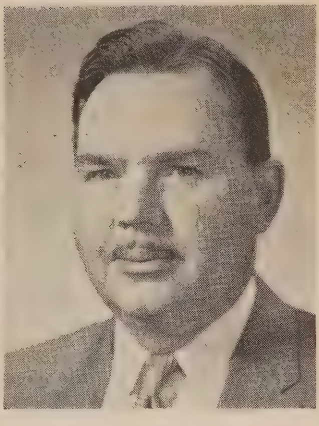
For contributions to communications engineering.

New Fellows



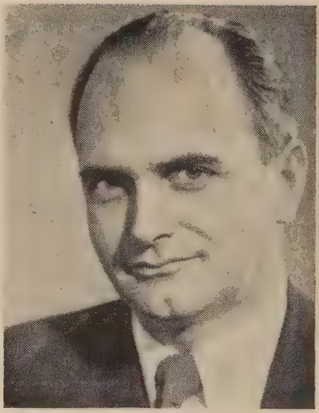
E. O. Johnson

For contributions to gaseous electronics and semiconductors.



Harwick Johnson

For contributions to the development of electron devices.

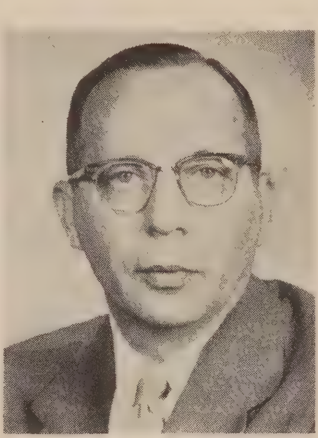


E. A. Keller

For contributions to sound recording and telephone switching systems.

C. L. Kober

For application of electronic techniques to defense systems.



Harry Krutter

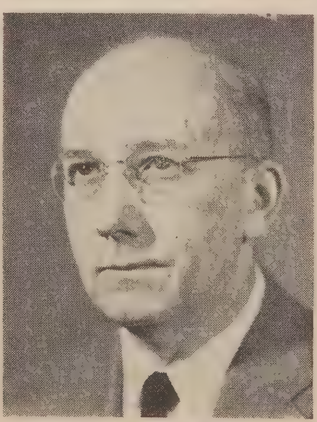
For contributions to defense electronics.

J. G. Linvill

For contributions to network theory and transistor circuits.

W. A. Lynch

For contributions to engineering education.



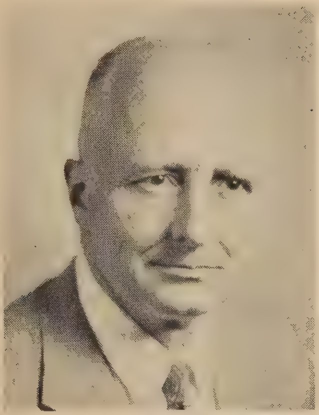
J. M. Manley

For contributions to the theory of modulators and parametric amplifiers.

M. A. McLennan

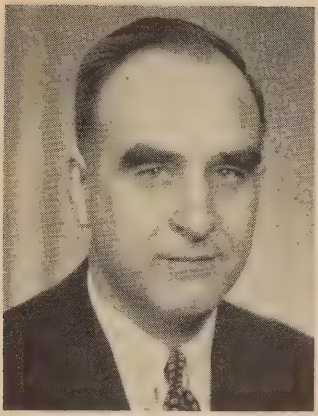
For contributions in aero-medical elec tronics.

New Fellows



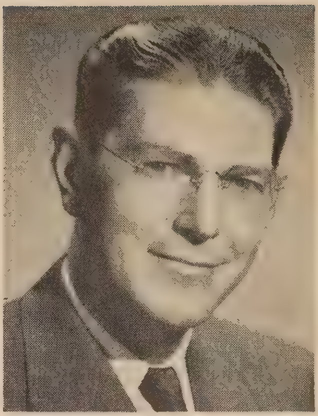
Doren Mitchell

For contributions to long-distance communications systems.



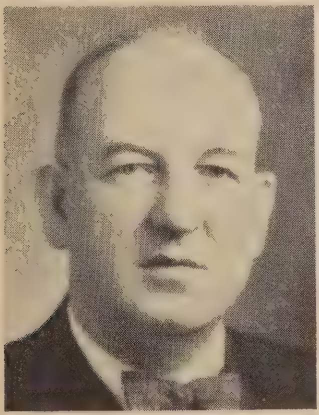
J. P. Molnar

For contributions to gaseous and solid-state electron devices.



L. H. Montgomery, Jr.

For contributions to medical electronics.

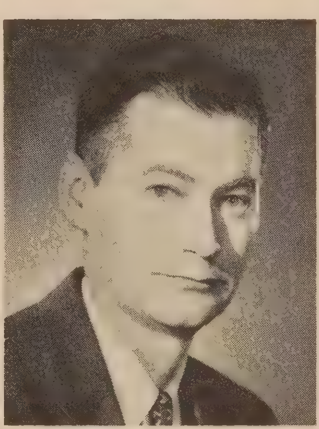


John B. Moore

For improvements in communications coding techniques.

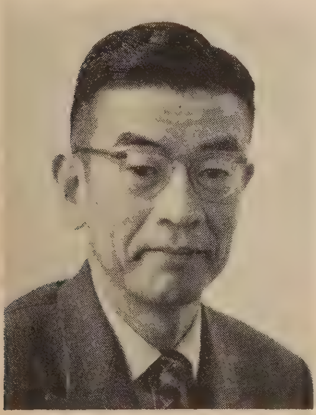
Theodore Moreno

For contributions in the field of microwave electronics.



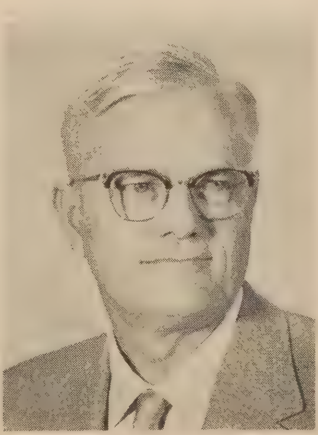
T. H. Morrin

For the administration of research in electronics.



Shogo Namba

For contributions to the understanding of ionospheric radio propagation.



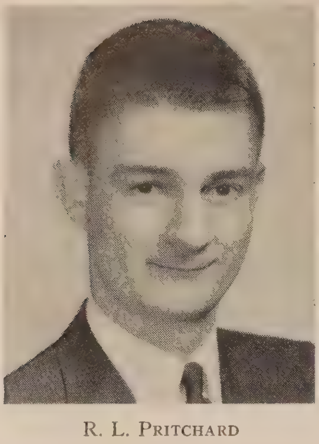
F. R. Norton

For contributions to radar and television.

Franz Ollendorff

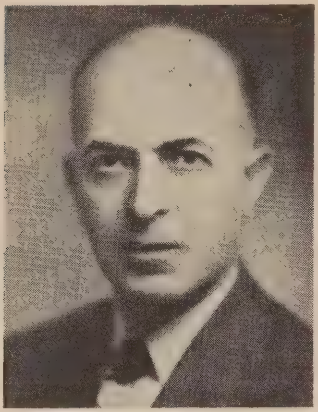
For contributions to electromagnetic theory and engineering education.

New Fellows



R. L. Pritchard

For contributions in the field of transistor circuits



R. L. Rau

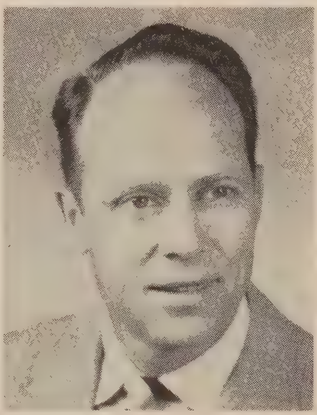
For contributions to international radio communications systems.

L. L. Rauch

For contributions to the theory and practice of radio telemetry.

H. R. Reed

For contributions to engineering education.



V. C. Rideout

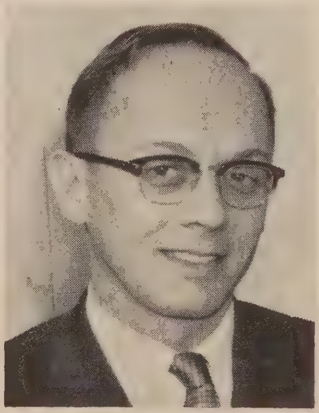
For contributions in the fields of microwave and computer education.

A W Rogers

For contributions in the development of electronic components.

V. H. Rumsey

For contributions to antenna theory and practice.



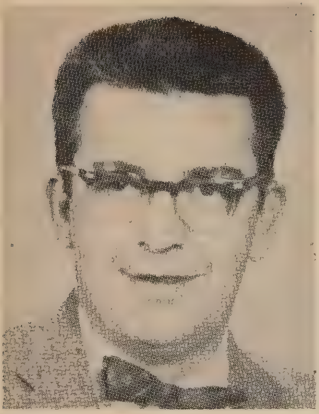
W T. Selsted

For contributions to the art of magnetic recording.

Samuel Sensiper

For contributions in the fields of microwave instrumentation and radiation.

New Fellows



William Sichak

For contributions to the techniques of microwave transmission.

R. L. Sink

For contributions to the field of digital instrumentation systems.

P. T. Smith

For contributions to the development of high-power transmitting tubes.

A. H. Sommer

For contributions in the field of photoemissive surfaces.

R. C. Spencer

, For contributions to the theory of microwave antennas.

W. E. Tolles

For the application of electronics to the field of medicine.

L. G. Trolese

For contributions to the understanding of radio wave propagation.

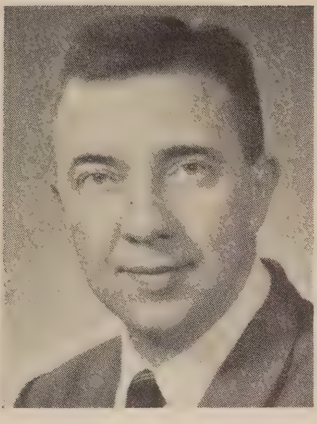
D. F. Tuttle, Jr.

For contributions to network theory and education.

G. E. Valley, Jr.

For contributions to military systems engineering.

New Fellows



J. A. Van Allen

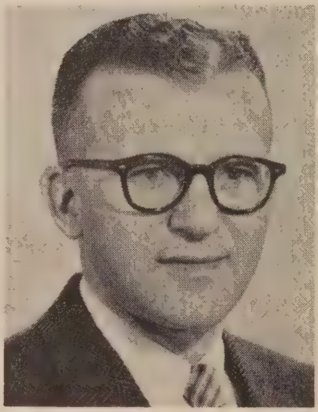
For the experimental discovery and exploration of radiation belts around the earth.

E. A. Walker

For services as an engineering teacher and administrator.

W. M. Webster, Jr.

For contributions to gaseous electronic and solid-state devices.



Louis Weinberg

For contributions to the field of network theory.

Books

Acoustique Musicale, Colloques Internationaux du Centre National de la Recherche Scientifique

Published (1959) by the Editions du Centre National de la Recherche Scientifique, 13, Quai Anatole France, Paris 7^{e}, France. 259 pages. $7\times 8\frac{3}{4}$. (In French.) 3.400 fr.

This volume contains the research papers presented at a three day international colloquium on musical sound, held at Marseille in 1958. One section of ten papers is about musical scales and harmony matters. The other section of thirteen papers is concerned with the physics of stringed and wind instruments. Electronics is involved only in the research instrumentation for spectrum analyses and frequency measurement. Nevertheless, an engineer interested in electronic means for music production, or for music reproduction, will find interesting and worthwhile basic information here about the traditional tone sources and the characteristics of their output waves. Among the musical instruments studied are the violin, cello, guitar, harmonium, pipe organ, French horn, trumpet, flute, clarinet, saxophone, bass horn, piano, and the human voice. The treatment of each instrument could not be comprehensive in one volume (or colloquium), but is illustrative and indicative of the possibilities for further research. The authors are from England, France, Germany, Hungary, Iran, the Netherlands, the USA, and the USSR.

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The Baldwin Piano Company
Cincinnati, Ohio

Electron Tube Circuits, by Samuel Seely

Published (1958) by McGraw-Hill Book Co., Inc., 330 W. 42 St., N. Y. 36, N. Y. 657 pages+14 index pages+21 appendix pages+xi pages. Illus. $6\frac{1}{2}\times 9\frac{1}{4}$. $10.50.

This book has been written for electrical engineering students in the fourth year of the electrical engineering curriculum. It consists of some 657 pages exclusive of appendixes and index and is to a large extent identical to the preceding volume (first edition). Some thirty-five pages of new material on semiconductors and transistor circuit applications have been added.

The author covers the same topics that were covered in the first edition with some change in the order and with the material on feedback organized in a separate chapter. There is also some reorganization in the chapters on oscillators and relaxation oscillators. New material has been added, in addition to the treatment of semiconductors and transistors, with respect to feedback and the effect of inverse feedback on the effective internal impedance of an amplifier. The discussion of internal impedance is considerably improved and expanded. The analysis of the cathode follower as a sample of the feedback circuit is very well done. A decided improvement has been made in Chapter 8 in the analysis of the difference amplifier. New material has also been included in the chapter on electronic computer circuits on the solution of simple differential equations. This chapter has 23 problems of which 10 are either identical with or slightly different from the problems in the old text.

Most of the new material is to be found in the expansion of the treatment of electron tube circuits. To a large extent the problems remain unchanged except for the addition of a few problems in most chapters, as for example Chapter 11, Tuned Potential Amplifiers, where the 29 problems include seven new problems added to the original 22 used in the corresponding chapter of the old text. A considerable improvement has been made in portions of the treatment of tuned power amplifiers.

The author makes a somewhat obvious effort to avoid the use of the word voltage, using potential instead. He also uses the term electron tube to refer to and to include all types of electron devices including transistors.

The author provides introductory treatment of the physical basis for semiconductor diode and transistor behavior as circuit components. The space provided for this treatment is not adequate for a satisfactory presentation. His development of the equivalent circuit of the transistor is related to the method used for tube equivalent circuits but is not so complete or satisfying. No mention is made of the h-parameters. Four terminal network theory is not adequately introduced and its usefulness is not made clear.

In summary, the second edition of this text provides a thorough and improved treatment of electron tube circuits. It does not, however, provide an integrated treatment of transistor and tube circuit theory with the proper distribution of emphasis in the semiconductor field.

E. M. BOONE
Ohio State University
Columbus, Ohio

Information Transmission, Modulation, and Noise, by Mischa Schwartz

Published (1959) by McGraw-Hill Book Co., Inc., 330 W. 42 St., N. Y. 36, N. Y. 454 pages+7 index pages+xv pages. Illus. $6\frac{1}{4}\times 9\frac{1}{4}$. $11.00.

A concomitant of progress in any field is the gradual assimilation of previously esoteric material into earlier and earlier stages of the university curriculum in that field. Thus, in electrical engineering, the almost incomprehensible electromagnetic theory of eighty-five years ago is now meat for sophomores, and juniors and seniors are regularly exposed to the abstrusenesses of the modern form of network theory originating some thirty years ago. We are currently in the process of absorbing into the undergraduate electrical engineering curriculum the fruits of two decades of research into the application of statistical techniques to communication and control system design. The present book is a much-needed step in this process.

At present, a course in probability theory is, unfortunately, not generally required in the beginning years of an electrical engineering education—a situation which assuredly will change. Without the benefit of such a prerequisite course, however, and given only one semester in the senior year in which to teach communication theory, the question is: what should be taught? The answers to this have largely been the unsatisfactory extremes either of concentrating on classical probability theory and statistics, with perhaps some vague indication of the connection of all this abstract basic material to communication systems, or of concentrating on *ad hoc* systems, without giving an underlying statistical approach to the theory of communication systems in general. Professor Schwartz has now given us an excellent compromise solution.

In the first chapter, the author, by relying predominantly on the student's intuitive understanding of probability, gives a very brief introduction to the notions of information content and system capacity. He shows that two principal features of a communication system which limit its ability to transmit information by means of a physical signal are the maximum rate at which it will allow the signal to change, and the number of different signal states which the system can distinguish. The study of these features forms the unifying theme of the book. The first, related to the bandwidth of the system, is investigated in Chapter 2, in which are considered the Fourier analysis of signals and the effects of linear systems on signals. The second is related to the noise in the system, the nature and origins of which are studied in Chapter 5; here, for simplicity, noise is characterized only by its mean and mean-square values, which, defined as time averages, are easily related to the student's previous experience with time averages for nonrandom waveforms.

Chapters 3 and 4 form a detour into the detailed analysis of several conventional information transmission systems, both of the sine-wave (AM and FM) and pulse (PAM and PPM) modulation types. These chapters, interesting per se, are the more so for providing a background for Chapter 6, "Comparative Analysis of Information-Transmission Systems," which in many respects is the *pièce de résistance* of the book. Drawing together the results of the preceding five chapters, the author in this chapter compares the previously discussed conventional systems on the basis of the exchange relationship each exhibits between output signal-to-noise ratio and bandwidth. He shows that although some of these systems are more desirable on this basis than others, none approaches the performance predicted by information-theoretic considerations. This leads to a discussion of coded modulation schemes, and PCM in particular.

A lengthy final chapter is obviously—and both necessarily and regrettably—a postscript to the book, not intended for inclusion in the course. It is a superior, self-contained primer on the use in systems analysis of probability theory and statistics, the details of which had previously been avoided.

Professor Schwartz writes very lucidly indeed. He makes especially deft use of heuristic and intuitive arguments to focus attention on fundamentals and to clarify topics which are apt to be conceptually confusing for the beginner. Inevitably, there are a few minor features of organization with which this reviewer might disagree, and a modicum of those errors to which books, no matter how carefully written, seem to be prone. But in view of the over-all excellence of the book, to dwell on these would be mere carping. To those seeking a text which gives an elementary engineering insight into modern communication theory, this book is most highly recommended.

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Hughes Research Labs.
Culver City, Calif.

Advances in Space Science, Volume I, Frederick I. Ordway, III, Ed.

Published (1959) by Academic Press, Inc., 111 Fifth Ave., N. Y. 3, N. Y. 382 pages+16 index pages +14 appendix pages+xii pages. Illus. $6\frac{1}{4}\times9\frac{1}{4}$. $12.00.

The book is a collection of six articles and an appendix by separate authors. These are:

1. Interplanetary Rocket Trajectories—by Derek F. Lawden
2. Interplanetary Communications—by J. R. Pierce and C. C. Cutler
3. Power Supplies for Orbital and Space Vehicles—by John H. Huth
4. Manned Space Cabin Systems—by Eugene B. Konecci
5. Radiation and Man in Space—by Herman J. Schaefer
6. Nutrition in Space Flight—by Robert G. Tischer

Appendix. A Decimal Classification System for Astronautics—by Heinz Hermann Koelle.

It is written for the space scientist who may be a specialist but desires to have a working knowledge of his associated fields. By existing standards it represents a rather thorough treatment of each of the six subjects presented. Much of the material in the first chapter was prepared as a report by Radiation Incorporated on an Air Force contract. Trajectories are considered mainly as a transfer between orbits which is generally predicated upon minimum propellant consumption and minimum time of flight criteria. The second chapter treats both the communications to other planets in space vehicles and to a satellite repeater, repeating signals back to the earth. The basic problems of the communications, the recent advances and the requirements of space systems are discussed in some detail. Typical systems are presented in terms of information bandwidth, transmitter power, antenna directivities, and receiver sensitivity. The third chapter treats power sources in the light of the space environment and the requirements of space vehicles. It considers both primary power sources and conversion techniques which include electrochemical systems, turbogenerators, magnetohydrodynamic conversion, thermocouples, thermionic conversion devices, quantum conversion techniques, (solar cells), and fission-electric conversions. Present state-of-the-art capabilities are outlined in some detail. In the fourth chapter many problems of the man in a space capsule are treated, including that of the closed life cycle. Specific methods of sustaining life in a space cabin are suggested and experiments are described. In "Radiation and Man in Space" an introduction is given on the effect of radiation upon human tissue. Then, the types and intensity of radiation near the earth and in space are treated in some detail. In the chapter "Nutrition in Space Flight" all problems of nutrition are treated from the standpoint of the closed cycle cabin system. Human needs for nutrition and human wastes are described, together with experiments which have been conducted in this field. In the Appendix, the classification adopted by the International Astronautical Federation is given under 90 General Headings and 900 Detailed Headings.

Conrad H. Hoeppner
Radiation, Inc.
Melbourne, Fla.

Our Sun, by Donald H. Menzel

Published (1959) by Harvard University Press, Cambridge 38, Mass. 340 pages+10 index pages. 201 figures. $6\frac{1}{2}\times9\frac{3}{4}$. $7.50.

This is the second and revised edition of the Harvard Astronomy Series book on the sun. The first edition appeared ten years ago. The text and illustrations are for the most part unchanged, although there are numerous revisions, modifications, and additions. In fact, there are twenty-three additional illustrations bringing the total to over 200. These include many recent photographs and spectra of the sun.

The author is now the Director of the Harvard Observatory and is widely known and respected for his outstanding theoretical contributions to astrophysics and for the impact that he has had on solar astronomy in this country.

The text is easy to read and can be understood throughout by an undergraduate student of engineering; it can be read with profit by any engineer interested in the scientific aspects of the sun. Nearly every aspect of solar observation is included: the early history of solar observations, the basic elements of chemistry, physics, spectroscopy, radio observations, ionospheric measurements, and atomic energy. The text concentrated principally on the description of the physical characteristics of the sun such as rotation, energy generation, sunspots, faculae, prominences, granules, flares, formation of solar absorption and emission lines, limb darkening, reversing layer, chromosphere, corona, spicules, solar magnetic fields, the relationship of solar activity to geomagnetic storms, auroras, solar cosmic rays, terrestrial weather, the uses of solar energy, and the relationship of the sun to the stars.

The instruments of optical observations and the techniques of solar measurements are simply described. The details of about 200 solar eclipses occurring in the twentieth century are given in groups according to each individual saros epoch. This is an interesting table to study in order to acquaint oneself with the patterns of solar eclipses.

This book is not a treatise, it does not use mathematics and there are no references to the literature. A large number of solar astronomers are mentioned, but the choice clearly reflects the author's personal approach. For example, Barbara Bell, a colleague, is referred to as often as are Professors Unsold and Minnaert combined.

Solar radio astronomy is sketchily presented and the material given doesn't properly represent the amount of effort in this field. No mention is made of the exciting work going on in Paris and Tokyo, for example.

This is an excellent introductory book on the sun for the engineer. It is lucidly written and well illustrated.

Fred T. Haddock
University of Michigan
Ann Arbor, Mich.

Digital and Sampled-Data Control Systems, by Julius T. Tou

Published (1959) by McGraw-Hill Book Co., Inc., 330 W. 42 St., N. Y. 36, N. Y. 587 pages+7 index pages+11 bibliography pages+25 appendix pages. Illus. $6\frac{1}{4}\times9\frac{1}{4}$. $15.00.

In the field of sampled-data control systems a great amount of literature has appeared, but only a very few books have been published. This book takes its place along with the others as a notable contribution in bringing together the appropriate information. It is an excellent book.

The most notable features of this book are the logical development of the material, the manner in which various problems are faced up to, and the ease with which many of the topics are presented. The material reaches quite a bit beyond the theoretical and analytical aspects of sampled-data systems and touches on many of the practical problems such as quantization, analog-digital conversion, and specific circuit design considerations. In this respect one might ask why digital computer equipment and design was by-passed, but one readily visualizes the limitations on length of an already large volume.

In presenting the material the author assumes a strong reader background in control systems and servomechanisms. As a refresher, Chapter 2 summarizes this background material; but in an effort to condense, this chapter suffers from lack of clarity in places. The root-locus method for continuous data systems is probably the best part of this background material.

In dealing with sampling the author does not always distinguish between pulse and impulse modulations (*e.g.*, in the table of z-transforms, an impulse remains an impulse after impulse modulation), but here one can blame the negligence prevalent throughout the literature. What is nice in the exposition of both the methods and theories is the logical sequence in which problems are brought up and in the methods presented for their solutions. Somewhat too much emphasis is placed on Nyquist plots and their role in sampled-data analysis, but the use of root-locus and Bode plots is nicely stressed to balance the prevalent approaches in the literature. The theory of z-transformation is handled quite thoroughly and with considerable insight. System design, error analysis, and the use of error coefficients are treated. Statistical methods are used in several places and developed to at least a moderate extent.

The book shines not so much by its originality, but by the balanced bringing together of a wide variety of relevant methodology in a logical fashion. The amount of material presented is great, and the details are more often clarifying than cumbersome. It is clear that the author made a critical examination of the relevance and usefulness of the various methods, and in this reviewer's opinion he has exercised sound judgment in gaging their place and importance.

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Encyclopedic Dictionary of Electronics and Nuclear Engineering, R. I. Sarbacher, Ed.

Published (1959) by Prentice-Hall, Inc., 70 Fifth Ave., N. Y. 11, N. Y. 1417 pages+x pages. Illus. $7\frac{1}{4}\times10\frac{1}{4}$. $35.00.

This book is truly an encyclopedic work, embracing, as it does the electronic and nucleonic fields. It obviously represents a thorough scanning of the definitions promulgated by the leading military and professional sources and includes over 14,000 terms.

The dictionary has been written for engineers primarily, and particular effort has gone into the nuclear portion in an attempt to clarify nucleonic terms for the electronics engineer who wishes to enter this new field. Thus the reader will find many of the nuclear items expanded, with considerable explanatory matter.

There are profuse illustrations, including many drawings of various types of reactors, and typical schematic diagrams for various electronic circuits, also drawings illustrating construction of many common electronic components.

This reviewer has made a spot check of the material in several fields and is of the opinion that there is a wide variation in timeliness in these fields. In addition, this work suffers from the same fault that occurs so frequently where an author chooses to paraphrase existing standards. In many places the text gives credit to the IRE for a particular definition, yet there are various changes in the wording of the existing IRE Standard. While the basic meaning may not have been altered, the author has lost sight of the fact that these are no longer official IRE Standards and thus have no official authority.

The reviewer must also take exception to the statement on the dust cover "This is the ONLY single source to provide you with *all* the standard definitions approved by official technical societies." In view of the liberties taken with a large percentage of the IRE definitions checked this statement is obviously misleading.

To comment on specific sections: The nuclear portion was drawn previously from the ASME Glossary of Terms in Nuclear Science and Technology, interspersed with some IRE definitions (some altered) and others. Unfortunately, the above-mentioned Glossary is not widely accepted and was issued as a preliminary standard, pending a more definitive effort which is currently under way in the ASA. Thus this dictionary perpetuates a number of terms which are obviously inadequate. As an example, the various definitions of *Plateau* and related terms are restricted to Geiger counters, whereas in the IRE Standards these definitions apply to Radiation Counter Tubes, a much more inclusive category.

Some liberties have been taken with standard ASA and IRE symbology, *e.g.*, T is occasionally used for time, which should be designated by t, T being used for temperature.

In the semiconductor field, the book leaves much to be desired. There are numerous errors, *e.g.*, a diode is defined as "a two-electrode electron tube," although examples of semiconductor diodes are listed; in the definition of *diffusion length* the term *majority carriers* should be *minority carriers*. The transistor material is about five years out of date, all the equations being given in terms of the T-equivalent circuit, whereas today's texts and specification sheets use the hybrid h parameters almost exclusively.

Finally, the reviewer noted this amazing statement: "Standardization of transistor schematic symbols for point contact and junction transistors has not been attained." The text then proceeds to use both graphical and letter symbols at variance with the standardized IRE forms. The writer would have been better informed if he had consulted the IRE in this respect, as these items have been standardized since 1956 and 1957.

Despite these glaring errors, the book is still an important contribution to the art, provided the reader bears one thing firmly in mind: it is a dictionary, a glossary, definitely *not* a compendium of standard definitions, hence cannot be quoted or used with any official exactness. The reader who wants complete rigor in his definitions must refer to the official works of the respective technical societies. This particular society, the IRE, cannot give official sanction to the definitions ascribed to it, for the obvious reasons illustrated above.

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Radar Meteorology, by Louis J. Batten

Published (1959) by The University of Chicago Press, Chicago 37, Ill. 154 pages+7 index pages+xi pages. Illus. $6\frac{1}{4}\times9\frac{1}{2}$. $6.00.

This book will serve to acquaint the radar designer with the pertinent characteristics of weather which effect the propagation of microwave energy through the atmosphere. Also, meteorologists who desire to know more about the use of radar as a meteorological tool will find this book useful. There is a wealth of references throughout the book, which enhances its usefulness to those doing research as well as to the radar designer and the synoptic meteorologist. The author states in the preface that his purpose is one of . . . "briefly describing in one small volume the progress made since the birth of radar meteorology" This he has done in a well organized manner.

The book starts with a short chapter on some of the basic principles of radar, apparently directed at the meteorologist. The following five chapters are devoted to a more detailed consideration of the properties and propagation of electromagnetic waves, the use of the radar equation for determining power returned from reflecting spherical particles, scattering from nonspherical particles and factors which influence the attenuation of electromagnetic waves.

Chapter seven covers the use of radar as a means of providing quantitative measurements of precipitation. Following this is a short discussion of the types of distortions which are to be expected as a result of having finite pulse lengths and beamwidths. The effects of antenna sidelobes are also mentioned.

With chapter nine the book begins to devote more to the meteorological aspects of "Radar Meteorology." It briefly describes mechanical, photographic and electronic methods of integration used in conjunction with rain gauges for determining the amount of rain falling over an area. The next chapter is concerned with the use of radar for cloud physics research. It covers such items as detection of precipitation in, and growth of, convective clouds, diameter and duration of convective echoes, the "bright band" phenomenon, precipitation generating levels and the use of radar for assessing results of cloud seeding.

The use of radar as a means of obtaining otherwise unavailable information on thunderstorms, squall lines and tornadoes is discussed in some detail in chapter eleven. This is followed by a discussion of the use of airborne radar in aircraft operations as an aid toward reducing flight hazards.

In recent years radar has proved to be valuable in the study and prediction of the behavior of hurricanes and other large weather systems. A discussion of the information obtained by radar from such weather phenomenon is covered in chapter thirteen. This is followed by a short chapter on radar echoes (angels) which may occur during the absence of precipitation. The book concludes with a description of special techniques, such as isoecho contouring and stepped grey scale, which may be used in conjunction with the existing radar circuits to enhance the usefulness of the radar set as a meteorological device.

While this is not a profound book, it will serve to acquaint the uninitiated with the possible uses of radar for meteorological purposes. The author has done an excellent job of providing references to books and papers that are pertinent to the subject of Radar Meteorology.

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Scanning the Transactions

Single-sideband goes underwater. SSB enthusiasts may be be interested to know that single-sideband suppressed-carrier transmission has proved to be the only effective system for underwater communication. FM is entirely unsuited to transmitting acoustic energy through water because phase disturbance of the wave components becomes so great that the essential characteristics of the signal are completely destroyed. Conventional AM is subject to undesirable fluctuations in the signal due principally to the presence of the carrier. Suppressed-carrier SSB has provided the most satisfactory answer. A mobile system recently designed for use between a hovering helicopter and a submarine had the following rather typical performance characteristics: a carrier frequency of 8 kc, modulation frequency of 200 to 3000 cps, transmitted power of 20 watts, and a range of 5,000 to 10,000 yards. An interesting feature of the receiver, one which simplified the design and minimized the problem of signal drift, was the use of a double heterodyning system for recovering the signal in place of the usual process of generating and reinserting the carrier into the incoming suppressed-carrier signal. (N. D. Miller, "An underwater communication system," IRE TRANS. ON COMMUNICATIONS SYSTEMS, December, 1959.)

A new look in phonograph needles may be in the offing. While the change may not be detectable to the eye, it will be to the ear. The tips of present day needles are in the shape of a hemisphere having a radius of 0.5 to 1.0 mil. Unfortunately this shape, while convenient to fabricate, does not correspond to the shape of the stylus used to cut records. This difference causes tracing distortion during playback, an effect which can be reduced by decreasing the radius of the needle tip, but only at the expense of increasing the wear and tear on the record. The new needle being proposed is in the shape of a pyramid, closely resembling the shape of the cutting stylus. This new shape, while more costly to produce, results in less distortion and background noise and longer life for recordings, both monaural and stereophonic. (C. D. O'Neal, "The pyramid stylus," IRE TRANS. ON AUDIO, November-December, 1959.)

Ultrasonic welding celebrates its tenth birthday this year. It is still a poorly understood process, although ultrasonic welders have been successfully designed by trial and error methods for limited applications. Until the basic principles of the process are better known, however, the development of equipment will continue to be empirical and the limitations of the process will remain unknown. What is believed to be the first fundamental study of the mechanisms involved in ultrasonic welding has now been reported. It appears that the welding process, in which surfaces subjected to a clamping action are welded when made to slide in contact with each other, is directly related to the well-known frictional phenomena of galling and seizing. This study also disclosed how clamping force, duration of weld cycle, ultrasonic motion, and temperature are related to weld strength. Present indications are that practical ultrasonic butt, seam, and spot welders can be designed for welding thin-gauge sheets or small components of ductile materials. (J. N. Antonevich, "Ultrasonic welding equipment," IRE TRANS. ON ULTRASONICS ENGINEERING, February, 1960).

Choosing the best type of communication system for a particular application is neither a purely technical problem nor a purely economic one, but a complex combination of these two factors. One engineer with considerable experience in this field has devised a novel formula for rating one system against another which takes both factors into account. This rating formula provides a good first-order approximation of the relative merits of various systems, making it possible to narrow down the number of systems that must be analyzed in greater detail. The formula for system performance rating is given by

$$\text{SPR} = \frac{\text{number of repeaters} \times \text{error rate}}{10^3 \times \text{available bandwidth (mc)} \times \text{availability}} \times \log_{10} (\text{TPR} \times \text{RPR} \times 10^7),$$

where TPR (transmitter power rating) is equal to transmitter power × antenna gain/bandwidth (cps); RPR (receiver performance rating) is equal to receiver antenna gain/[receiver noise figure] × [bandwidth (cps)]; and "availability" is the fraction of the time that the transmission medium is available for use. The lower the system performance rating is, the more desirable it is, *i.e.*, the lower the cost is. It will be interesting to see how well this evaluation technique, which thus far has checked out well, stands the test of time and experience. (J. H. Vogelman, "Comparative evaluation of communications transmission media," IRE TRANS. ON COMMUNICATIONS SYSTEMS, December, 1959.)

The radiation tolerance of electronic components is receiving a growing amount of attention in the design of equipment for both civilian and military applications. A number of organizations have been exploring the effects of radiation on standard components for the past several years. The results of these investigations, reported in over 600 scattered documents, have now been compiled in a single information file. By means of this file it has been found possible to modify existing equipment by selective replacement of radiation-sensitive parts with standard parts having a higher radiation tolerance. With this approach, circuits remain essentially unchanged, yet the amount of radiation the equipment can withstand has been raised orders of magnitude. Thus while more radiation data is still needed, it appears we have now reached the point where radiant-tolerant equipment can be successfully built with what is presently known, without need for extensive radiation testing. (J. R. Burnett, "Radiation-tolerant electronic equipment," IRE TRANS. ON NUCLEAR SCIENCE, December, 1959.)

The development of new low-noise amplifiers has changed the emphasis in communication system design from considerations of receiver noise to considerations of external noise. The noise level of a maser can be as little as one-thousandth that of a conventional amplifier. The question arises how much of this improvement is actually realized in an operating system and how much is lost to external noise. The answer has now been worked out at least for one type of system—a tropospheric scatter system operating in the 1000 to 2000 mc range. It has been found that the cooled-crystal technique will provide a system improvement of 3 db, the parametric amplifier 9.5 db, and the maser 12 db. When the problems associated with liquid helium operation of masers are taken into account, it appears that the parametric amplifier is the best choice. (A. Feiner and D. Savage, "The effects of low-noise techniques on tropospheric scatter communications," IRE TRANS ON COMMUNICATIONS SYSTEMS, December, 1959.)

Abstracts of IRE Transactions

The following issues of TRANSACTIONS have recently been published, and are now available from the Institute of Radio Engineers, Inc., 1 East 79th Street, New York 21, N. Y. at the following prices. The contents of each issue and, where available, abstracts of technical papers are given below.

Sponsoring Group	Publication	Group Members	IRE Members	Non-Members*
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Aeronautical and Navigational Electronics

Vol. ANE-6, No. 4, December, 1959

Frontispiece (p. 210)

Airborne Dual Antenna System for Aerial Navigation—W. Spanos and J. M. Ashbrook (p. 211)

This paper describes a 1000-mc dual antenna system which uses parallel-driven sector antennas. Methods for determining the performance in pattern interference regions are given together with applications to DME, Radar Safety Beacon and TACAN navigation systems. A flyable-model dual antenna system for Constellation and DC-6 type aircraft is described. Provision of an RF hybrid permits the simultaneous operation of two navigation equipments, such as DME and Radar Safety Beacon, from the same antenna system. A prototype of this antenna system on a DC-3 has provided improved performance for the TACAN navigation system. Flight tests with an experimental dual antenna system have shown improved performance for DME and Radar Safety Beacon systems. The results of flight tests show agreement with theoretically determined values of performance.

The Indeterminacy of Measurements Performed by Radar Equipment—R. Madden (p. 219)

A theoretical derivation of the indeterminacies of simultaneous position and velocity measurements of a reflector when using reflected electromagnetic waves is given. It is shown that the product of the indeterminacies is given by $1/(8\pi)/\lambda_S c$ where λ_S is the illuminating wavelength and c the speed of light. It is shown that the necessary consequence of nonsimultaneous measurements is an uncertainty as to whether the measurements are common to the same reflector. If this uncertainty is to be overcome, the reflectors must be spaced at a distance $\frac{1}{2}c\Delta T$ where ΔT is the time separation of the position and velocity measurement.

Principles of Electronic Navigation Systems—P. C. Sandretto (p. 221)

Electronic navigation systems of all types are discussed, and classified as classical or self-contained. The error rates and accuracies of the various systems are discussed.

Anticipatory Display Design Through the Use of an Analog Computer—L. J. Fogel and M. Dwonczyk (p. 228)

Modern high-performance aircraft currently are pressing the limitations of the human operator. The increased speeds compress the allowable reaction time to such levels wherein logical decisions, and even conditioned reflex actions, may no longer be possible. The only way to overcome this human limitation of manned aircraft performance is through the incorporation of anticipatory displays; displays which offer a prediction of the various parameters so that the human operator is projected ahead of the system. An aircraft was analog computer simulated, data reduction was programmed and the same computer was used to allow biophysical measurement, which furnished correlative measure. The effectiveness of various piloting techniques, as well as prediction intervals, was explored. The results indicated a first approximation to the design of improved displays through the use of anticipatory information.

PGANE News (p. 240)

Contributors (p. 242)

Annual Index, 1959 (follows p. 242)

Audio

Vol. AU-7, No. 6, November/December, 1959

The Editor's Corner (p. 137)

PGA News (p. 139)

The Pyramid Stylus—C. D. O'Neal (p. 140)

A new shape for a phonograph needle stylus is described which greatly improves the reproduction possibilities from phonograph records. The new stylus was specifically produced for use with 45°–45° stereo recordings, but will perform equally well on all microgrooved monaural recordings. The scheme described evolves a shape of reproducing stylus having a basic geometry relating to the cutting stylus used in forming all microgrooves. Computations, experimental data and charts are also used to support the improvements to be expected in reproducing reproduction performance.

Time-Frequency Scanning in Narrow-Band Speech Transmission—D. L. Subrahmanyam and G. E. Peterson (p. 148)

Two basic sampling methods for the transmission of intelligible speech with reduced channel capacity have previously been studied. The channel vocoder developed by Dudley is based on frequency band separation or quantization, and Schisser, and Fairbanks, Everitt, and Jaeger have developed a technique of time sampling. Sampling in both time and frequency offers a third major possibility which should be investigated.

For this study a narrow-band speech transmission system was constructed which scans the time-frequency plane. The system scans in either a sinusoidal or in a sawtooth manner over a frequency range of 200 to 7000 cps. In order to achieve the scanning, a variable carrier frequency oscillator, having a frequency shift of ±30 per cent of the carrier frequency and an amplitude modulation of ±2 db, has been developed. The process of scanning leaves empty spaces in the time-frequency plane, and a four-channel time-delay system which employs the method of dielectric recording has been used to fill the gaps in the time-frequency plane by repeating the signal samples.

When signal reiteration is employed with this system, a score of 75 per cent of monosyllabic phonetically balanced word lists was obtained with a scanning filter of 1000-cps bandwidth and a sinusoidal scanning rate of 30 times per second. This intelligibility is appreciably higher than that which can be achieved with a fixed 1000-cycle filter located in the frequency region of maximum intelligibility.

Circuits for Three-Channel Stereophonic Playback Derived from Two Sound Tracks—Paul W. Klipsch (p. 161)

Derivation of a third playback channel from two stereo sound tracks may be accomplished by several means. The center channel may be derived by recombination prior to power amplification; acoustically, after amplification, by using two center speakers; and in a variety of phase relationships, including the limiting case of equal signals (monophonic) in which either sum or difference combination may be chosen by polarity selection.

Characteristics of Degenerative Amplifiers Having a Base-Emitter Shunt Impedance—William D. Roehr (p. 165)

In amplifiers having emitter degeneration, an impedance is sometimes used between base and emitter. A common case occurs when several emitter followers are used in cascade. The resistors become necessary in order to provide some measure of stability.

In an audio amplifier of similar design it became necessary to know what effect this shunt resistor would have upon the input impedance of the stage. As a result, the analysis given in this paper was performed. Experimental measurements which support the resulting equation are given.

This analysis and these measurements led to the discovery of a circuit which would exhibit a high ac input impedance, yet the resistors in the dc base circuit could be kept low to provide good stability. Although it can be shown that circuit power gain is the same regardless of whether a resistor is used in series with the emitter or the base to obtain a high input impedance, considerations of dc stability and distortion demand a more thorough investigation of this problem.

Design principles are outlined for this high input impedance stage and an example is worked out in detail. Supporting measurements are given.

Correspondence (p. 169)

Contributors (p. 170)

Annual Index, 1959 (p. 172)

Communications Systems

Vol. CS-7, No. 4, December, 1959

Frontispiece and Guest Editorial (p. 227)

Comparative Evaluation of Communications Transmission Media—Joseph H. Vogelman (p. 230)

The selection of communications transmission media for any specified operation is neither a purely technical problem nor a purely economic one, but a complex combination of these two factors. To minimize work involved in evaluating all the possible choices, a first-order approximation method is provided to limit the number of specific transmission media which must be considered in any specific application. This method provides a numerical measure of the expected combination of technical and economic factors and is based on the author's empirically-derived experience with communications equipments and systems.

Design Considerations for Space Communication—J. E. Bartow, *et al.* (p. 232)

With the advent of Russian and American artificial earth satellites, the use of such vehicles for communication purposes has been the subject of considerable study both by military and commercial organizations in the communications field. The purpose of this paper is to delineate the problems involved in space communication, the assumptions that must be made and the technical limitations which determine the communication system that should be used for a particular time frame. Some characteristics for an optimum system are stated. Some technical characteristics of the first successful satellite communication system are given.

Development Trends in USAF Global Communication Systems—C. A. Strom, Jr. and A. A. Kunze (p. 241)

This paper briefly summarizes one initial development approach for the 1962–1965 USAF Global Communications Systems. A brief review is given of some of the early communications systems work and the present design philosophy for the 600-voice bandwidth channel, 6000-mile trunk system is discussed. Specific requirements of the ground-based Air Force common-user system are listed and developments intended to provide much of the equipment for this time period are noted. This paper concludes that by adopting the system approach, the Air Force will be provided with a greatly increased communications capability at a total cost which differs little from today's annual expenditure.

An Underwater Communication System—Norman D. Miller (p. 249)

Communications between submerged submarines and surface craft require energy to be propagated through sea water. The only practical method for transmitting this energy is by acoustic means. Both FM and AM transmission systems have been used, but for long-range communication, a single-sideband suppressed-carrier transmission system is the only effective way of propagating sound energy. The requirements for the transmission system and diagrams of the circuitry are given.

Wide-Band Facsimile Transmission Over a 900-Mile Path Utilizing Meteor Ionization—W. H. Bliss, *et al.* (p. 252)

Preliminary tests of facsimile transmission over a 910-mile path have been made at 40 mc by means of intermittent meteor ionization. Printed matter was scanned at a rate of 2 frames per second, with a resolution of 67 elements per inch. An all-electronic facsimile system recorded a picture when the received signal rose above a preset threshold.

Tests were conducted employing bandwidths up to 110 kc with keying frequencies up to 73 kc, still maintaining the same optical resolution in the facsimile material. With the equipment used in the tests, it appeared that the maximum bit rate for acceptable facsimile was about 48,000 bits per second at 2 per cent duty cycle and about 86,000 bits per second at 1 per cent duty cycle. Examples of signal recordings with received facsimile are shown.

Preparations are being made to conduct similar tests, employing a higher information rate and wider bandwidth, on a frequency near 50 mc.

A Very High-Speed Facsimile Recorder—G. M. Stamps and H. C. Ressler (p. 257)

An operating facsimile system is described which is capable of transmitting black and white graphic information at the rate of 24 inches of copy feed per second. The system uses conventional line-by-line sequential scanning at the transmitter and a multistylus recorder with 100 lines per inch resolution at the receiver. The electrolytic recording medium employed is characterized by a relatively low internal impedance, which permits close spacing of the stylus electrodes and the use of direct-coupled transistors for the individual marking amplifiers. The high transmission speed results from the use of individual stylus electrodes for each elemental area along the scanning line and the holding of the video marking signal at each stylus for time intervals approximating the duration of a complete scanning line. The system described uses a 100-stylus block assembly, restricting the length of the scanning line to one inch. One thousand-stylus block assemblies have been made and these will permit reproduction of copy 10 inches wide.

The NBS Meteor Burst Communication System—R. J. Carpenter and G. R. Ochs (p. 263)

This project was undertaken in 1955 to investigate the properties of the intermittent reception of VHF signals over long distances by meteoric propagation and their communication usefulness. To accomplish this, a complete duplex teletype system operating at about 50 mc was constructed, and results are reported from tests made over a 1277-km east-west path. Comparisons are made of burst transmissions of 10, 20, 40, and 80 times normal teletype speed and of variations in a number of control system parameters.

For the system under test, the optimum speedup was 40×, which produced a daily average channel capacity of about 40 wpm with a character error rate of about 0.0035 (with the best control system settings). Higher speedup ratios are advocated for future systems. The most serious causes of outages in this type of system are atmospheric noise and sustained multipath distortion from competing modes such as E_s and auroral propagation.

White Alice System—Design and Performance—A. L. Durkee, *et al.* (p. 272)

White Alice is an extensive communications network covering the entire state of Alaska. It provides essential defense communications as well as service for other government agencies and civilian commercial service. Both telephone and telegraph channels are provided with capacity for future growth. The Western Electric Company, as prime contractor for the USAF AMC, undertook the engineering, procurement, and installation of the electronic equipment as well as construction of some of the sites.

The Bell Telephone Laboratories participated in the basic systems engineering and furnished consulting assistance in new scientific areas. New designs were made or supervised by the Laboratories. The White Alice system plan is based on the study by the Bell System of the communications needs of the area.

Radio transmission was chosen for the majority of the routes. Wire and cable were considered either unreliable or impractical in the Alaskan terrain and climate. Where several hundred voice channels were required, microwave line-of-sight radio was used. For the majority of the links, tropospheric beyond-horizon transmission was used because of the economy and simplification of maintenance and logistic problems.

The transmission objectives for the entire system were a median noise in the worst month of 38 dba and a maximum of 1 per cent outage in the worst month. These objectives were for 4000-mile circuits and were prorated to each link.

The microwave portions of the system were engineered in the same way that has been used previously. Tropospheric beyond-horizon was a relatively new mode of radio transmission and the engineering procedures were less well defined. Propagation experience from a year-long test in Newfoundland, in addition to research by other groups, was used as the basis for the system engineering. These data include variation of signal strength from day to day and seasonally, the effective gain of the large antennas employed, the characteristics of the rapid fading typical of tropospheric propagation, and the effects of geographical profile and separation of the stations.

Towards the completion of the project, comprehensive transmission tests were made of many of the links of the system to determine that the design objectives had been met. In particular, a 2400-mile circuit traversing much of the system was tested. The transmission stability and noise performance over a 30-day period was well within the limits set in the objectives. Teletype and voice performance were eminently satisfactory.

White Alice has been operating continuously since it was turned over to the Air Force in March, 1958. Its reliability has been gratifying to the military and other agencies using it. It is certain to be a significant factor in the development of this last frontier.

Installation and Operational Aspects of a Private Television Microwave System—Aaron Shelton (p. 278)

The problems of installation, operation and maintenance of a 165-mile, six-hop, private, intercity television relay system are reviewed. Careful planning of the path to be used is required. Equipment, its housing, power and frequency chosen for this service require careful evaluation. Emergency power supplies are required. Numerous modifications to commercial equipments were found necessary. The problems of sound diplexing through a multihop system proved difficult, but possible and worthwhile. Careful maintenance schedules and techniques developed for checking operation of each station proved their value. Communications for a multihop system become very important. Manpower required for a system of this magnitude proved to be greater than expected. Equipments designed and field checked for multihop installations can only be considered if truly dependable service is required and expected.

Practical Considerations in the Design of Minimum Bandwidth Digital Frequency Modulation Systems Using Gaussian Filtering—W. L. Glomb (p. 284)

The characteristics of a digital frequency modulation system are reviewed. The Gaussian frequency response is specified and optimum filters for transmitter and receiver (both predetection and postdetection) are developed. The relationship between peak deviation and system threshold is explored and an optimum deviation established. The location of the Gaussian filters in the system is discussed. It is shown that for best threshold performance, all receiver filtering should be predetection filtering and that optimum peak deviations under these conditions may correspond to the −4-db point of the IF filter. Practical details of transmitter and receiver design are discussed.

These results have been applied to a 2000-mc communication equipment.

A Study of the Technical and Economic Feasibility for Tropospheric Scatter Circuits in Primary Toll Networks of Underdeveloped Countries—C. A. Parry (p. 290)

The inherent capabilities of the tropospheric scatter circuit have emphasized the need for careful economic and technical evaluation. It is suggested that this should be carried out in two phases. The first is a broad study which determines the essential system parameters for which detailed analysis is necessary. The second phase is concerned with this detail. Outlines are given relevant to the principal factors associated with the first of these phases. These cover such areas as trunk circuit growth, required channel, capacity at the end of the amortization period, revenue potential, optimum routing, choice of transmission method, and the optimum number of tandem tropospheric scatter links. The performance sacrifice for a minimal cost "first in" system and the manner in which design accuracy may be traded against probable propagation reliability are two of the problems discussed. Evaluation of the scatter link may be based on a performance index and data relevant to this are given. It is concluded that adequate analysis of the modern system capability requires a sophisticated engineering approach for which the present paper is a guide.

50-kw Antenna Switching System—John W. Smith (p. 295)

There are many HF radio installations today that illustrate the need for an improved antenna switching technique. Today there is a growing requirement to connect rapidly any one of several 50-kw transmitters to any one of many antennas. An antenna switching system must be broad-band, convenient to use, fast, safe for operating personnel, and free of appreciable impedance discontinuities. This paper describes several components and techniques that solve the transmitter-antenna selection problem up to a 50-kw power level. The influence of switching techniques on RF transmission, impedance conversion and antennas are also discussed.

The Effects of Low-Noise Techniques on Tropospheric Scatter Communications—A. Feiner and D. Savage (p. 302)

This paper defines the expected benefits to be derived from the use of low-noise receiver techniques when applied to tropospheric scatter systems in the 1000- to 2000-mc range. Calculations were made of the expected antenna noise temperatures for "smooth" and "rough" ground locations. These data, plus the known and anticipated performance of various low-noise techniques, permitted the calculation of increased sensitivity. The sensitivity improvement is then expressed in terms of increased range, decreased transmitter power, and decreased antenna size.

Contributors (p. 307)

Education

VOL. E-3, NO. 1, FEBRUARY, 1960

Editorial (p. 1)

The Research Flavor—John S. McNown (p. 2)

Research should be made a significant part of undergraduate engineering education in order to orient the student toward the solving of new problems. He should learn of the frontiers of his field of study, and should know of the people who are pushing back these frontiers.

An increase is needed in the number of courses designed for guiding a student to define problems, to make assumptions, to search for his own methods of solving them, and to develop a way to report his findings. Almost as a dividend, new ideas and the exercise of originality provide a strong motivation to learning.

The Scientific Manpower Shortage and Its Implications for the Engineering Technician—John Merrill (p. 3).

Some of the background of the present scientific manpower shortage is reviewed. Utilization as an important aspect of engineer efficiency is discussed. With this setting, the engineering technician's complementary function with the engineer is introduced. The limited availability of technicians is cited. A discussion of the *stepping-stone* aspect of the technician job, an area worth consideration because of its ramifications, is presented and the concept of a four-year program for engineering technicians is shown to have significant value in coping with several phases of technician training.

Four areas of study and investigation are suggested that can contribute to solution of the over-all need of increased scientific manpower through increased utilization. Utilization would be improved by the proper preparation of an adequate number of engineering technicians.

Circuit Analysis—A Problem in Semantics—Thomas M. Adams (p. 10)

The teaching-learning process in circuits is enormously complicated by the multiple meanings and shades of meanings which are inherent in most of the technical terms. A method is offered for reducing every term relating to "functions" to its basic meaning for the particular circuit application under study. Using this method, which might be called "current analysis," it becomes possible to explain detailed circuit phenomena to students with little or no technical or mathematical background.

A General Course in Traveling Waves—R. K. Moore (p. 15)

Traveling waves must be considered whenever the time for a disturbance to propagate from one place to another is important. A course with this as its theme has been developed to replace the usual course in transmission lines or distributed constant circuits. Emphasis is placed on the transmission line as a teaching vehicle, but plane waves in space; vibrating strings and membranes; acoustic waves in gases, liquids and solids; heat conduction; and chemica diffusion are also treated. The analogies between the "telegraphers' equations" and comparable equations describing nonelectrical phenomena are stressed.

Transients are treated for two special cases: 1) lossless lines and acoustics, and 2) diffusion and heat transfer. Steady state analysis using phasors and the Smith Chart is applied to plane electromagnetic and acoustic waves at all angles of incidence, as well as the transmission line. Spherical acoustic waves are treated briefly.

A First Course in Electrical Engineering—P. R. Clement and W. C. Johnson (p. 19)

This article describes the introductory two-semester course in electrical engineering that has been developed over a period of five years at Princeton University. The aims of the course are to provide an introduction to the field of electrical engineering via the basic concepts of electricity and magnetism (which are developed through Maxwell's equations in the integral form), to apply these concepts in developing the fundamentals of energy conversion and circuit theory, and to carry forward, in a continuous and integrated way, a modern treatment of network analysis. Thus, the treatment proceeds from field ideas to circuits and physical apparatus, and to their mathematical models. With the circuit relations formulated, attention turns to the analysis of networks, starting with network topology and extending through pole-zero ideas. The treatment stops just short of the Laplace transform. This course is intended to serve as a foundation for subsequent courses such as electronic circuits, energy conversion, and advanced network analysis and synthesis, and has been developed with the purpose of providing the student with a unifying point of view for these varied topics.

The Organization of a Laboratory Electronics Course—D. Blackwood (p. 22)

This paper describes the organization of a Laboratory Electronics Course in the Department of Aircraft Electrical Engineering at the College of Aeronautics, Cranfield, England. The course caters to two standards of specialization and to students with a wide range of previous training.

The minor specialization course concentrates solely on fundamentals and the basic concepts, while the major course is carried to the threshold of design procedures. The contents of both courses are limited to the student's previous training and the time available for practical work. The over-all standard of the major course is that of the M.Sc. degree of a British University.

Four different ways of construction and presentation of experiments are described and the limitations of each are discussed. Finally, the laboratory layout, equipment, and scheme of work for both courses is described.

A Supplementary DC Machine Test for Sophomores—E. Della Torre and C. V. Longo (p. 25)

A blocked-rotor test may be used to determine curves for a family of dynamic operating characteristics for dc machines. Conventional performance characteristics may be predicted from these curves. The authors have used this test procedure to supplement the usual tests on machinery in the sophomore laboratory. The new procedure emphasizes the fundamental principles of machine operation and also points up the importance of certain details which have a significant effect upon performance. The test would logically precede the usual load tests. The latter are then anticipated with enthusiasm since they provide confirmation of performance predicted from the static tests.

Contributors (p. 29)

Information Theory

VOL. IT-5, NO. 4, DECEMBER, 1959

Frontispiece (p. 148)

Editorial (p. 149)

A Class of Systematic Codes for Non-Independent Errors—N. M. Abramson (p. 150)

A class of systematic codes has been obtained which will correct all single errors and all double errors which occur in adjacent digits. These codes use significantly fewer checking digits than codes which correct *all* double errors. In addition, because of inherent regularities in their structure, these codes may be instrumented in a strikingly simple fashion.

A Probabilistic Model for Run-Length Coding of Pictures—Jack Capon (p. 157)

A first-order Markoff process representation for pictures is proposed in order to study the picture coding system known as run-length coding (differential-coordinate encoding). A lower bound for the saving in channel capacity is calculated on the basis of this model, and is compared with the results obtained by previous investigators. In addition, this representation is shown to yield an insight into the run-length coding system which might not otherwise be obtained. The application of this probabilistic model to an "elastic" system of run-length coding is also discussed.

A Note on Invariant Relations for Ambiguity and Distance Functions—C. A. Stutt (p. 164)

Woodward's result for the ambiguity function, that the volume associated with its squared magnitude over the time-shift and frequency-shift plane is a constant, has been shown to be true also for a cross-ambiguity function for two time functions. If complex time functions have been obtained by means of a Hilbert transformation from real time functions, it is found for the cross-ambiguity function that the volumes under the squared real part and under the squared imaginary part are constant and contribute equally to the volume under the squared magnitude function. A "distance" function for two time functions is defined to be the integrated squared difference between these functions. The relation for the squared real part of the ambiguity function readily yields an invariant relation for the volume associated with this distance function in the case of Hilbert-derived complex time functions. An especially simple invariant relation for the "mean" distance, as computed over the time-shift and frequency-shift plane, exists for such time functions having finite energy and finite mean value.

On Upper Bounds for Error Detecting and Error Correcting Codes of Finite Length—Nelson Wax (p. 168)

Upper bounds for error detecting and error correcting codes are obtained in this paper. One upper bound is found by exploiting the geometrical model of coding introduced by

Hamming. The volume of an appropriate geometrical body is compared with the volume of the unit cube, in getting the first upper bound. An improvement on this upper bound can be found by introducing a mass density function, and comparing the mass of the body with the mass of the unit cube.

A comparison is made with known upper bounds, and with best codes found thus far. The improved upper bound given here is frequently somewhat smaller than previously known upper bounds.

The Probability Density of the Output of an RC Filter When the Input Is a Binary Random Process—H. A. McFadden (p. 174)

A new method is given for obtaining the probability density of the output of an RC filter when the input is a stationary binary random process. The axis-crossing intervals of the input are assumed to be statistically independent and identically distributed, but with an arbitrary density function. The method involves a linear integral equation which can be reduced by Laplace transforms. A new family of solutions is given which includes two previously known cases: the random square wave of Poisson type, and the periodic square wave with random time origin. The general result of this family is given in terms of tabulated functions. For other solutions, a recursive technique may be necessary.

Recurrent Events in a Bernoulli Sequence—M. B. Marcus (p. 179)

The "point of regeneration" method is used to obtain simple sequential equations for determining the complete probability density function for multiple occurrences of events in a Bernoulli sequence. Both the independent and overlapping classes of recurrent events are included in the general framework of these equations. The equations also lead to the generating function for the probability distribution. This is used to obtain the expected recurrent times for the different classes of recurrent events.

A distinction is made between the probability distributions for the occurrence of the kth event at the nth trial and the occurrence of k events in n trials. The latter case is of primary concern.

The methods employed and the results obtained have extensive applications in problems in automatic control, communications, and information processing.

Correspondence (p. 184)
Contributors (p. 191)
Annual Index, 1959 (follows p. 191)

Nuclear Science

Vol. NS-6, No. 4, December, 1959

Effects of Reactor Exposure on Boron-Lined and BF$_3$ Proportional Counters—William M. Trenholme (p. 1)

The results of reactor exposure on the characteristics of several types of boron-lined and BF$_3$-filled proportional counters are presented, and the important design and application criteria that lead to improved performance of counters after long reactor exposure are discussed.

The Describing Function of Nuclear Reactors—Henri B. Smets (p. 8)

The integro-differential equation of reactor dynamics is studied and approximated. It is found that a reactor can be represented by means of a linear system and a nonlinear system in cascade. The transfer function of the linear system is the classical low-power transfer function. The nonlinear system is a nonlinear amplifier with an exponential characteristic. The describing function is computed in the case of a water-moderated reactor and it is shown that gain near resonance increases with the magnitude of a reactivity sinusoidal oscillation.

Radiation-Tolerant Electronic Equipment—James R. Burnett (p. 12)

Transistor-Driven Beam Switching Tube Decade Counter—Richard H. Graham (p. 16)

This paper describes an electrical readout decade counter employing the magnetron beam switching tube with transistor drive. Double-pulse resolution is 1 μsec. The unit will accept a variety of transistor types, and will tolerate supply voltage variations of ±20 per cent at ambient temperatures up to 60°C. A "Pixie" neon indicator is driven without the use of additional transistors. A readout circuit for printer or punched paper tape is presented.

A Stack Effluent Radioisotope Monitor—R. A. Harvey (p. 20)

A system for simultaneously measuring and indicating each of several different radioisotopes in the stack effluent of an atomic energy facility is described. Analog computer techniques are employed for the solution of simultaneous equations and for the counting and scaling. Two types of presentations are included for the output. The total amounts of the radioisotopes emitted to the atmosphere are indicated on registers, and marks are recorded on a moving chart each time specific quantities are emitted. The emission quantity of each isotope is indicated by a register and by a single channel on the chart recorder.

Ultrasonics Engineering

Vol. 7, PGUE-8, February, 1960

Transducer Properties of Lead Titanite Zirconate Ceramics—D. Berlincourt, *et al.* (p. 1)

Physical properties of two commercial ceramics of the lead titanate zirconate family are presented and are compared with data for typical barium titanate ceramics. The importance of dielectric losses is stressed. Preference is given to showing heat generated as a function of nonresonant strain amplitude rather than electric-field amplitude. In this type of presentation, common barium titanate ceramics vary little from each other, while lead titanate zirconate ceramics are quite outstanding.

Thickness-Shear Mode BaTiO$_3$ Ceramic Transducers for Ultrasonic Delay Lines—John E. May, Jr. (p. 7)

The properties of thickness-shear mode BaTiO$_3$ ceramic transducers as applied to ultrasonic delay lines have been investigated. A method of fabricating these transducers has been developed which allows bonding to the delay line by conventional soldering techniques. Compared with thickness-extensional mode transducers, the shear mode transducers have a higher dielectric constant, a lower resistance and a lower capacitance ratio. Substitution for the former on short delay lines at 15 mc increased the bandwidth from 30 per cent to 43 per cent for the same loss. When the quartz transducers on the longer polygon-type lines were replaced with the ceramic transducers, the loss was reduced from 40 db to 20 db.

Vibrations of Ferroelectric Transducer Elements Loaded by Mass and Acoustic Radiation—F. Rosenthal and V. D. Mikuteit (p. 12)

The motion, stress distribution, and electrical impedance are calculated for idealized three-layer sonic transducers, consisting of a piezoelectric element loaded at either end by a mass which may be distributed or lumped, and loaded further by resistive plane-wave acoustic radiation. The piezoelectric element may be driven by use of either the d_{33} or d_{31} effect. The lumped constant equivalent circuit is given for the case of lumped end masses and negligible ceramic mass density. The lumped mass solutions are compared with the somewhat more realistic solution based on the assumption of distributed end masses (obtained on an IBM 650 computer).

Effect of Electrical and Mechanical Terminating Resistances on Loss and Bandwidth According to the Conventional Equivalent Circuit of a Piezoelectric Transducer—R. N. Thurston (p. 16)

This paper includes a rather complete analysis of transducer loss and bandwidth as a function of the mechanical and electrical terminations. For the case of tuning with a shunt coil, Fig. 1 shows lines of constant loss at midband and curves of constant bandwidth plotted with the electrical and mechanical terminations proportional to ordinate and abscissa, respectively. Besides enabling one to find quickly the loss and bandwidth corresponding to any pair of terminations and to visualize the effect of termination changes, this plot also reveals quickly the terminations which have special properties, such as zero loss at midband, zero minimum loss, widest band for a given loss, etc. The case of a series tuning inductor is treated by making use of an approximate correspondence with the shunt case. Results to be expected without a tuning inductor are also indicated.

Ultrasonic Welding Equipment—John N. Antonevich (p. 26)

Little or no work has been reported on investigations into the basic principles of ultrasonic welding. Until these principles are understood, the development of ultrasonic welding equipment will continue to be empirical and the limitations of the process will remain unknown. What is believed to be the first fundamental study of the mechanisms involved in ultrasonic welding has been started. On the basis of observations made in this study, it is postulated that this new welding process is a form of pressure or friction welding, in which material surfaces subjected to a clamping force are welded when made to slide in contact with each other. The process appears to be related directly to the frictional phenomena of galling and seizing.

The relationships between weld strength and the variables of clamping force, duration of weld cycle, ultrasonic motion, and temperature, have been obtained for a Monel sphere welded to a copper plate. This work shows that there is a minimum displacement and temperature required for welding. Also, that weld strength is directly proportional to clamping force, displacement, weld time, and temperature, up to critical values of these variables. Under conditions where critical values are exceeded, weld strength is decreased, apparently because of fatigue about the weld zone. The minimum displacement required for welding agrees with displacements calculated to be necessary to produce sliding.

The fundamental study shows that the essential components of an ultrasonic welder are: 1) an arrangement to clamp together members to be welded, 2) an arrangement to couple vibratory energy to one of the members being welded, 3) a controllable source of vibratory energy, and 4) a timing circuit to control the duration of clamping force and vibratory energy. On the basis of conditions found necessary to produce a weld, the problems encountered in designing welder components are discussed and methods of circumventing them are presented. To improve weldability of materials, welders could be developed to weld materials in vacuo or in an inert atmosphere. This would reduce oxidation around weld zones caused by frictional heating. A control circuit differentiating the temperature at or near the weld site could also be incorporated in ultrasonic welders to control the process and insure uniformity of strength of welds. Present indications are that practical ultrasonic butt, seam, and spot welders can be designed, but they would be limited in application to welding thin-gauge sheets or small components made of ductile materials.

Correction (p. 32)
Contributors (p. 33)

Abstracts and References

Compiled by the Radio Research Organization of the Department of Scientific and Industrial Research, London, England, and Published by Arrangement with that Department and the *Electronic and Radio Engineer*, incorporating *Wireless Engineer*, London, England

NOTE: The Institute of Radio Engineers does not have available copes of the publications mentioned in these papers, nor does it have reprints of the articles abstracted. Correspondence regarding these articles and requests for their procurement should be addressed to the individual publications, not to the IRE.

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The number in heavy type at the upper left of each Abstract is its Universal Decimal Classification number. The number in heavy type at the top right is the serial number of the abstract. D.C. numbers marked with a dagger (†) must be regarded as provisional.

U.D.C. NUMBERS

Certain changes and extensions in U.D.C. numbers, as published in PE Notes up to and including PE 666, will be introduced in this and subsequent issues. The changes are:

Artificial satellites:	551.507.362.2	(PE 657)
Semiconductor devices:	621.382	(PE 666)
Velocity-control tubes, klystrons, etc.:	621.385.6	(PE 634)
Quality of received signal, propagation conditions, etc.:	621.391.8	(PE 651)
Color television:	621.397.132	(PE 650)

The "Extensions and Corrections to the U.D.C.," Ser. 3, No. 6, August, 1959, contains details of PE Notes 598–658. This and other U.D.C. publications, including individual PE Notes, are obtainable from The International Federation for Documentation, Willem Witsenplein 6, The Hague, Netherlands, or from The British Standards Institution, 2 Park Street, London, W.1., England.

ACOUSTICS AND AUDIO FREQUENCIES

534.2-8-14 722

Propagation of Finite-Amplitude Ultrasonic Waves in a Relaxing Medium—V. A. Krasil'nikov and D. V. Khaminov. (*Akust. Z.* vol. 5, no. 2, pp. 166–169; 1959.) Investigation of ultrasonic propagation at frequencies of 0.5, 1 and 2 mc in acetic acid at various concentrations.

534.2-8-14 723

Optical Investigations of the Waveform of Large-Amplitude Ultrasonic Waves in Liquids—V. A. Shutilov. (*Akust. Z.*, vol. 5, no. 2, pp. 231–240; 1959.)

A list of organizations which have available English translations of Russian journals in the electronics and allied fields appears at the end of the Abstracts and References section.

The Index to the Abstracts and References published in the PROC. IRE from February, 1959 through January, 1960 is published by the PROC. IRE, June, 1960, Part II. It is also published by *Electronic Technology* (incorporating *Wireless Engineer*, and *Electronic and Radio Engineer*), and included in the April, 1960 issue of that journal. Included with the Index is a selected list of journals scanned for abstracting with pulishers' addresses.

534.2-8-14 724

Propagation of an Acoustic Pulse in an Underwater Sound Channel—N. S. Ageeva (*Akust. Z.*, vol. 5, no. 2, pp. 146–150; 1959.) Investigation of the waveform of 3-ms ultrasonic pulses propagated over distances up to 20 km underwater. Recordings of these pulses are compared with ray diagrams corresponding to the experimental conditions. The pulse shape is observed to vary with the distance from the emitter.

534.213-8 725

Velocity and Attenuation of a Narrow-Band, High-Frequency Compressional Pulse in a Solid Waveguide—M. Redwood. (*J. Acoust. Soc. Amer.*, vol. 31, pp. 442-448; April, 1959.) The Pochhammer-Chree solution does not correctly describe the propagation phenomena. A modification of the equations is proposed.

534.22-13 726

Velocity of Sound in Relaxing Gases—H. J. Wintle. (*Nature*, vol. 184, suppl. no. 26, pp. 2007–2008; December 26, 1959.) Measurements were made on pure CO$_2$, O$_2$ and dry air free from CO$_2$ of the velocity of sound and corresponding attenuation at frequencies in the range 100–1500 cps at a pressure of one atmosphere and a temperature of 30°C.

534.231 727

A New Method of Solving the Problem of a Sound Field in a Fluid Wedge—V. K. Kuznetsov. (*Akust. Z.*, vol. 5, no. 2, pp. 170–175; 1959.) Results are examined for the case of absolutely reflecting boundaries of the wedge. The theory indicates a new phenomenon of normal-wave refraction in the wedge with application to hydroacoustic shore refractions.

534.232-8 728

Dependence of the Gain of an Acoustic Focusing System on Sound Intensity—K. A. Naugol'nykh and E. V. Romanenko. (*Akust. Z.*, vol. 5, no. 2, pp. 191–195; 1959.) An expression is obtained for estimating the effects of nonlinear distortion in a focusing system on the amplification coefficient. Miniature receivers are used in investigating the waveform near the focus and the amplification coefficients of three BaTiO$_3$ focusing radiators operating at 0.5, 1.4, and 2.2 mc.

534.26 729

Diffraction of a Convergent Cylindrical Wave by a Cylinder—I. N. Kanevskiĭ. (*Akust. Z.*, vol. 5, no. 2, pp. 151–156; 1959.) A mathematical analysis of the diffraction of waves on an infinite cylinder disposed coaxially with the front of the wave. A comparison is made with the case of scatter of a plane wave on a cylinder of small circumference compared to the wavelength.

534.4 730

Theory and Practice of Vibration Analysis in the Transient Regime—L. Pimonow. (*Ann. Telecommun.*, vol. 13, pp. 100-111 and 125–152; March/April and May/June, 1958.) An analyzer based on the physical characteristics of the ear is evolved.

534.612:621.352:541.135.6 731

Analysis of a Logarithmic Solion Acoustic Pressure Detector—A. F. Wittenborn. (*J. Acoust. Soc. Amer.*, vol. 31, pp. 475–478; April, 1959.) An approximate method is used which avoids solving the Navier-Stokes equation describing the fluid-flow and the convection diffusion equation for calculating the current.

534.75 732

Intensive Differential Thresholds for Octave-Band Noise—A. M. Small, Jr, W. E. Bacon, and J. L. Fozard. (*J. Acoust. Soc. Amer.*, vol. 31, pp. 508–510; April, 1959.) Report of an experiment to determine the differential thresholds for octave bands of noise of different center frequencies at various sensation levels.

534.75 733

Multiple Observations of Signals in Noise—J. A. Swets, E. F. Shipley, M. J. McKey, and D. M. Green. (*J. Acoust. Soc. Amer.*, vol. 31, pp. 514–521; April, 1959.) Information on the general properties of the hearing process is obtained from experiments on the gain in detectability resulting from repeated observations of a given signal in noise.

534.75:621.391 734

Indices of Signal Detectability Obtained with Various Psychophysical Procedures—Swets. (*See* 1013.)

534.76 735

Binaural Communication Systems: Preliminary Examination—I. Pollack. (*J. Acoust. Soc. Amer.*, vol. 31, pp. 81–82; January, 1959.) Report of an exploratory study of a binaural system with rejection filtering in which selective operations are transferred to the listener.

534.76 736

On the Localization of the Apparent Sound

Source in Two-Channel Stereophonic Transmission—V. S. Man'kovskiĭ. (*Akust. Z.*, vol. 5, no. 2, pp. 176–182; 1959.) Stereophonic tests carried out at frequencies of 200, 1000 and 6000 cps in reverberation rooms of volume 1600 and 1500 meters^3 are described. The dependence of the apparent position of the sound source on the difference in sound level and the coordinates of the listener's position is investigated.

534.78 737

Intelligibility of Reiterated Speech—D. J. Sharf. (*J. Acoust. Soc. Amer.*, vol. 31, pp. 423–427; April, 1959.) An attempt is made to increase the intelligibility of speech sampled in time (interrupted speech) by filling in the blank spaces with repetitions of the speech samples (reiterated speech). There appears to be little advantage in the technique.

534.78:621.391 738

Communication Efficiency of Vocoders—Billings. (*See* 1014.)

534.782 739

An Experimental Transistorized Artificial Larynx—H. L. Barney, F. E. Haworth, and H. K. Dunn. (*Bell. Syst. Tech. J.*, vol. 38, pp. 1337–1356; November, 1959.) A modified telephone receiver driven by a transistor relaxation oscillator, and powered by 10.4-volt Hg cells, is used to produce 0.5-msec pulses at the required pitch. The pitch can be changed and, in use, the telephone receiver is held against the throat.

534.79 740

The Relation between Loudness and the Sound Pressure on the Tympanic Membrane—G. Jahn. (*Hochfrequenz.*, vol. 67, pp. 69–72; November, 1958.) Subjective tests with specially developed equipment show that a given sound pressure at the membrane always results in the same loudness sensation irrespective of the shape of the external sound field.

534.845.1 741

Investigations on the Measurement of the Sound Absorption Coefficient in Echo Chambers—E. Steffen. (*Hochfrequenz.*, vol. 67, pp. 73–77; November, 1958.) The effect of the arrangement and shape of the absorbent material under test on the relation between measured and true absorption coefficients is investigated.

534.861:621.395.665.1 742

Contribution on the Reciprocal Control of Dynamic Range—Völz (*See* 1019.)

534.88 743

On the Detection of Signals in Nonstationary Noise by Product Arrays—J. B. Thomas and T. R. Williams. (*J. Acoust. Soc. Amer.*, vol. 31, pp. 453–462; April, 1959.) Two detection systems having multiple inputs each consisting of nonstationary noise and a stationary random signal are analyzed and compared on the basis of signal/noise ratio.

534.88 744

Correlation of a Finite-Distance Point Source—M. J. Jacobson. (*J. Acoust. Soc. Amer.*, vol. 31, pp. 448–453; April, 1959.) Errors in predicted source directions obtained with a two-receiver steerable correlation system are considered in relation to source distance.

534.88:621.396.965.4 745

Underwater Echo-Ranging with Electronic Sector Scanning: Sea Trials on R.R.S. Discovery II—D. G. Tucker, V. G. Welsby, L. Kay, M. J. Tucker, A. R. Stubbs, and J. G. Henderson. (*J. Brit. IRE*, vol. 19, pp. 681–696; November, 1959.) The general performance of the equipment and its ability to detect fish shoals is described, together with an account of the equipment design. See 3676 of 1958 (Tusher, *et al.*).

621.395.61.089.6:534.6–8 746

Absolute Calibration of Pitot Tubes and Microphones by means of Ultrasonics—V. Gavreau and A. Calaora. (*Ann. Télécommun.*, vol. 13, pp. 153–158; May/June, 1958.) A phase-difference technique for measuring the velocity of air flow is applied to the calibration of pitot tubes at low velocities. The technique is also applied to the absolute calibration of microphones at frequencies below 400 cps.

621.395.623.7:621.318.2 747

Loudspeaker Magnet Design—A. E. Falkus. (*Wireless World*, vol. 66, pp. 41–44; January, 1960.) Magnet design using capped cylindrical slugs of Alcomax III is described.

ANTENNAS AND TRANSMISSION LINES

621.372.2 748

Reflection Coefficients—R. A. Waldron and J. K. Skwirzynski. (*Electronic Radio Eng.*, vol. 36, pp. 464–465; December, 1959.) "The reflection and transmission coefficients are considered for reflecting surfaces which have the same medium on either side. It is shown that the reflection coefficient can be written cos $\theta \cdot e^{j\theta}$ and the transmission coefficient sin $\theta \cdot e^{j(\theta-\pi/2)}$, θ taking values between $-\pi/2$ and $+\pi/2$."

621.372.2.012.11 749

The Smith Chart—R. A. Hickson. (*Wireless World*, vol. 66, pp. 2–9 and pp. 82–85; January and February, 1960.) Derivation and uses of the chart are described.

621.372.2.09 750

Group Velocity and Energy Velocity of Electromagnetic Waves in Loss-Free Lines—W. Kleen and K. Pöschl. (*Arch. elekt. Übertragung*, vol. 12, pp. 567–569; December, 1958.) Energy velocity equals group velocity in two special models of loss-free delay line and in loss-free lines, in general, including those of periodic structure. This is not in agreement with the findings of Borgnis (696 of 1959).

621.372.8:621.77 751

Waveguide Bending Design Analysis—F. J. Fuchs, Jr. (*Bell Syst. Tech. J.*, vol. 38, pp. 1457–1484; November, 1959.) "The art of rectangular tube bending is analyzed, with particular attention being given to tube wall thickness variations. Effects of these variations on tool design are discussed and methods and formulas for determination of wall distortions are presented."

621.372.8.049.7 752

High-Pressure Microwave Window—A. W. Lawson and G. E. Smith. (*Rev. sci. Instr.*, vol. 30, pp. 989–991; November, 1959.) Two conically tapered single crystals of Al_2O_3, with small ends abutting, are used to effect simultaneously a high-pressure seal and a matched transformation from a standard 1-cm circular waveguide at atmospheric pressure to a circular waveguide terminated by a high-Q cavity resonator with an internal hydrostatic pressure up to 10^4 bars.

621.372.81 753

The Impedance Concept in Waveguide Theory—A. Guerbilsky. (*Ann. Télécommun.*, vol. 13, pp. 114–120; May/June, 1958.) Wave propagation studies are simplified by breaking down the propagated wave into uniform plane waves. The method is applied to a parallel-plate and a rectangular waveguide, each containing two dielectrics.

621.372.825 754

Ridge Waveguide Impedance—G. Duckworth. (PROC. IRE, vol. 47, p. 2121; December, 1959.) A simpler formula than that given by Mihran (2425 of 1949) is derived for the characteristic impedance.

621.372.831 755

Mode Conversion—L. Solymar. (*Electronic Radio Eng.*, vol. 36, pp. 461–463; December, 1959.) The electric intensities in the taper section and larger waveguide are determined, and the amplitudes of the spurious modes computed for the case of rectangular waveguides of different cross sections joined by a pyramidal tapered section. A simple formula relating the taper section length to the mode-conversion figure is derived.

621.372.831:621.317.373 756

Phase Measurements through Tapered Junctions—L. Lewin. (*Proc. IEE*, pt. B, vol. 106, pp. 495–496; September, 1959.) The electrical length of a tapered junction matched at the transitions to uniform waveguides is usually taken to be its physical length. A small correction, due to the cylindrical nature of the wave, is calculated theoretically.

621.372.852.22 757

Gyromagnetic Modes in Waveguide Partially Loaded with Ferrite—H. Seidel and R. C. Fletcher. (*Bell Syst. Tech. J.*, vol. 38, pp. 1427–1456; November, 1959.) Analysis is made of all the propagating modes of a vanishingly small rectangular waveguide partially filled with transversely magnetized ferrite. Each of these modes is shown to propagate in only one direction and to tend to be lossy. These properties are of use in the design of a nonresonance isolator.

621.372.855 758

Rectangular-Waveguide Loads—W. G. Voss. (*Electronic Tech.*, vol. 37, pp. 6–8; January, 1960.) Modifications to the construction and mounting of resistive-element dissipative strips when used either as fixed flat loads or as adjustable sliding terminations are described. The two loads are considered to be improvements on any previous design of low-power load, having particular application where a variation of voltage SWR is required over a wide range or where an extremely flat load is required.

621.396.67.095 759

Antenna Power Densities in the Fresnel Region—R. W. Bickmore and R. C. Hansen. (PROC. IRE, vol. 47, pp. 2119–2120; December, 1959.) Curves of maximum power density are presented as a function of distance from the antenna for typical aperture distributions.

621.396.677.43 760

The Horizontal Radiation Patterns of Rhombic Receiving Antennas for Short-Wave Transmission Paths—H. Bohnenstengel, W. Kronjäger, and K. Vogt. (*Nachrichtentech. Z.*, vol. 11, pp. 605–610; December, 1958.) Statistical methods were used to determine the horizontal radiation patterns of a rhombic with 115-meter sides at Eschborn receiving station, for frequencies 5, 10, 15 and 20 mc. Levels of side-lobe and backward radiation were also determined.

621.396.677.71 761

Pattern Synthesis for Slotted-Cylinder Antennas—J. R. Wait and J. Householder. (*J. Res. nat. Bur. Stand.*, vol. 63D, pp. 303–313; November/December, 1959.) Tchebycheff polynomials are used to calculate the distribution of excitation in phase and amplitude of the axial slots, arranged around the circumference of a vertical cylinder, which are necessary to produce the required beamwidth and side-lobe levels in the horizontal plane.

621.396.677.83 762

Passive Microwave Mirrors—R. G. Medhurst. (*Electronic Radio Eng.*, vol. 36, pp. 443–449; December, 1959.) Equations for the phase and amplitude of the near field, close to the main lobe axis, of the primary radiation are derived as modifications of the far-field expressions. Computation of the gain of the antenna-reflector system relative to the antenna alone is simplified; the results agree well with measurements and previously calculated results.

AUTOMATIC COMPUTERS

681.142 763

New Digital-Computer Techniques—(*Proc. IEE*, pt B, vol.106, pp. 444–469; September, 1959.) A report of specialist discussion meetings of the Measurement and Control Section of the IEE, February 16–17, 1959, dealing with character recognition, peripheral equipment, low-temperature storage and switching devices, and special aspects of logical design.

681.142 764

Study of Certain Errors in Analogue Computers—M. W. Overhoff. (*Ann. Télécommun.*, vol. 13, pp. 162–168; July/August, 1958.) Linear and nonlinear imperfections in adding and integrating circuits are related to errors in the solution of differential equations. Analog computers using only ac amplifiers are shown to be a practical proposition.

681.142 765

Electronic "Rotor"—J. S. Johnston. (*Electronic Tech.*, vol. 37, pp. 2–6; January, 1960.) A method is described for introducing the concepts of bearing and angle into fast Cartesian analog computations without the use of mechanical shafts and servomechanisms.

681.142:621.3.029.6 766

Microwave Computer Circuits—F. Leary. (*Electronics*, vol. 32, pp. 77–81; November 20, 1959.) Examples of the use of microwave components and techniques in the construction of simple high-speed computing elements are given. Main problems are the cost and complexity of the waveguide systems required.

681.142:621.376.22 767

Use of a Diode Ring as a Four-Quadrant Multiplier—R. H. Wilcox. *Rev. Sci. Instr.*, vol. 30, pp. 1009–1011; November, 1959.) The operation of a diode ring as a passive analog multiplier is analyzed. Tests show that an accuracy within 1 per cent is obtainable at input levels up to 150 mv.

681.142 768

Electronic Digital Computers [Book Review]—C. V. L. Smith. Publishers: McGraw-Hill, London, 443 pp. (*Electronic Tech.*, vol. 37, pp. 43–44; January, 1960.)

CIRCUITS AND CIRCUIT ELEMENTS

621.316.8:621.391.822 769

Noise of Resistors and Resistor Combinations without and with Load—K. Lunze. (*NachrTech.*, vol. 8, pp. 580–584; December, 1958.) Noise due to current flow in carbon-film-type resistors is particularly considered. The increase over thermal noise is controlled by a factor which depends on loading, film dimensions and the construction of the resistor; from this a formula is derived which contains a constant dependent on film material.

621.319.4 770

The Impedance of Non-quasistationary. Annular-Plate Capacitors—W. Buschbeck (*Telefunken Ztg.* vol. 32, pp. 23–28; March, 1959. English summary, p. 72.) The maximum permissible dimensions for the avoidance of self-resonance are calculated for high-frequency grid stopper and lead-through capacitors.

621.319.42.004.6 771

The Reliability and Life of Impregnated-Paper Capacitors—J. P. Pitts. (*Proc. IEE*, vol. 106, pp. 397–403; October, 1959. Discussion, pp. 403–408.) The construction of paper capacitors and the problems associated with failure in them are reviewed. Possible methods of prolonging life and reducing failures are discussed.

621.372.414 772

Coaxial Resonators with Helical Inner Conductor—W. W. Macalpine and R. O. Schildknecht. (Proc. IRE, vol. 47, pp. 2099–2105; December, 1959.) Resonators of small size can be designed for the VHF and HF ranges. Design formulas are simple, and have been confirmed by experiment.

621.372.44:621.372.6 773

General Energy Relations in Nonlinear Reactances—J. M. Manley and H. E. Rowe. (Proc. IRE, vol. 47, pp. 2115–2116; December, 1959.) An alternative derivation to that used earlier (2988 of 1956) is based on conservation of energy and the properties of the device.

621.372.44:621.372.6 774

A Simplified Derivation of the Manley and Rowe Power Relationships—J. E. Carroll. (*J. Electronics Control*, vol. 6, pp. 359–361; April, 1959.) *See* 773 above.

621.372.5 775

The Determination of Canonical Reactance Quadripoles with Prescribed Iterative Matrix—R. Unbehauen. (*Arch. elekt. Übertragung*, vol. 12, pp. 545–556; December, 1958.) The iterative matrix of any reactance quadripole is realized by means of canonical circuits (see, *e.g.*, 2354 of 1957). The method consists in developing a two-pole function into a continued fraction. This function represents the impedance of the two-pole network which results from terminating by unity resistance the output of a quadripole realizing the given matrix.

621.372.5 776

Applications of Wave Matrices for Calculations on Four-Terminal Networks with Transverse Symmetry—L. R. Yavich. (*Radiotekh. Elektron.*, vol. 4, pp. 341–344; February, 1959.) An extension of the method used in the classical theory of linear networks and based on bisecting the four-terminal network. See 2149 of 1959.

621.372.5:061.3 777

Modern Network Theory in Electrical Engineering—J. T. Allanson. (*Nature*, vol. 184, pp. 1691–1692; November 28, 1959.) Report of a conference held by the Department of Electrical Engineering of the University of Birmingham, September 22–24, 1959.

621.372.5:621.3.016.35 778

Some Considerations on the Stability of Electrical Circuits—I. Gumowski. (*Ann. Télécommun.*, vol. 13, pp. 121–124; May/June, 1958.) A definition of stability based on an integral equation is proposed. It is considered to be more general in applicability than the definitions of Bode and James and Weiss.

621.372.5:621.391.822:621.375.4 779

Contribution to the Theory of Noisy Quadripoles—R. Paul. (*NachrTech.*, vol. 8, pp. 548–568; December, 1958.) Detailed consideration of the parameters which determine the noise figure, particularly of transistors. The effect of circuit configuration on noise figure is discussed and typical circuit parameters for thermal-noise networks are tabulated. The noise characteristics of a single-stage transistor amplifier are investigated.

621.372.5.001.572 780

Transient Synthesizer—P. Eykhoff. (*Electronic Tech.*, vol. 37, pp. 31–36; January, 1960.) An instructional instrument is described which may be used to study the transient response of a quadripole of which the transfer function, in terms of poles and zeros, may be set immediately to the desired form.

621.372.51:621.375.42 781

Power Matching of Quadripoles with Complex Parameters—H. J. Butterweck. (*Arch. elekt. Übertragung*, vol. 12, pp. 540–544; December, 1958.) The passive matching impedances are derived which are required for maximum power amplification with quadripoles having complex parameters, such as transistors at high frequencies. A criterion is established for unconditional stability of a quadripole connected to passive impedances.

621.372.54 782

Monotonicity and Maximally Flat Rational Functions—T. R. O'Meara. (Proc. IRE, vol. 47, pp. 2116–2117; December, 1959.) It is shown that these functions describe the transmission properties for some common cases in loss-free filter design.

621.372.62 783

The Multipole Network with Symmetry of Terminal Number—W. Klein. (*Arch. elekt. Übertragung*, vol. 12, pp. 533–539; December, 1958.) Using matrix notation formulas are derived for crosstalk in multipole networks which have an equal number of input and output terminal pairs.

621.373:621.376.32 784

The Modulation of the Natural Frequency of a Loss-Free Oscillator Circuit—E. Kettel. (*Telefunken Ztg.*, vol. 31, pp. 254–261; December, 1958, and vol. 32, pp. 29–38; March, 1959. English summary.) The modulation can be represented by a Hill's equation. The properties of oscillator circuits with one or two controllable reactance elements are investigated, and equations of the ideal frequency modulator are derived.

621.373.4.029.65:376.23 785

Transistor Phase Detector for Phase-Lock Stabilization of a 30,000-Mc/s Klystron—R. W. Zimmerer. (*Rev. Sci. Instr.*, vol. 30, pp. 1052–1053; November, 1959.) A 15-mc reference signal is applied to the common emitters of two transistors with their bases driven in push-pull by the output of a 15-mc IF amplifier. A control signal is derived from the two collectors and is in series with the klystron repeller voltage supply. See 397 of 1958 (Thompson and Cateora).

621.373.42:621.316.729 786

Oscillator Synchronization at Combination Frequencies for the Purpose of Wide-Band Frequency Stabilization—G. M. Utkin. (*Radiotekh. Elektron.*, vol. 4, pp. 272–285; February, 1959.) Investigation of a system of three coupled oscillators, two of which are tuned to the natural frequency of the third oscillator.

621.373.42:621.316.729 787

Effect of an E.M.F. with Periodically Varying Parameters on an Oscillatory System——N. N. Lunacharskiĭ. (*Radiotekh. Elektron.*, vol. 4, pp. 286–294; February, 1959.) Mathematical analysis, based on the Ricatti equation with variable coefficients, to determine the phase variations in an oscillator with an applied EMF periodically varying in amplitude and frequency.

621.373.421.11 788

On the Possibility of Further Generalization in Quasilinear Theory of Single-Circuit LC Oscillators—P. G. Korolev. (*Radiotekh. Elektron.*, vol. 4, pp. 262–271; February, 1959.) A general expression is derived for the complex amplitude of the first harmonic of the oscillator anode current for a given tube characteristic and any arbitrary amplitude values of a synchronous or asynchronous EMF.

621.374.32:621.387.4 789

Millimicrosecond Discriminator—D. W. Swift and V. Perez-Mendez. (*Rev. Sci. Instr.*, vol. 30, pp. 1004–1006; November, 1959.) A discriminator circuit for use with counting equipment is described which has a good response to pulses as short as 3 mμsec.

621.374.34 790

10^{-9}-sec-Resolving-Time Coincidence Circuit-Limiting Effect in Electron Tubes—F. Lepri. (*Rev. Sci. Instr.*, vol. 30, pp. 1049–1050; November, 1959.) The operation of the circuit described is based on the formation of a virtual cathode between adjacent electrodes under positive grid conditions. Characteristic curves for a pentode Type E 180 F are shown. Tests performed on 50 tubes showed a spread of about 5 per cent in limited-current values.

621.374.4:621.372.44 791

Frequency Multiplication with Nonlinear Capacitors—a Circuit Analysis—D. B. Leeson and S. Weinreb. (Proc. IRE, vol. 47, pp. 2076–2084; December, 1959.) From the formulas given, it is possible to specify the optimum nonlinear characteristic for a given circuit and harmonic number, and to calculate the conditions for maximum efficiency. The procedure can be used for frequency division and for circuits with nonlinear inductors.

621.374.4:621.382.22 792

Two-Crystal Harmonic Generator—T. E. Hartman. (*Rev. Sci. Instr.*, vol. 30, pp. 1063–1064; November, 1959.) The Si crystals are small polished pieces of microwave-diode material with tungsten-wire cat whiskers. Input and output waveguides have their broad faces in contact. One whole crystal assembly is moved to tune the generator over the fundamental frequency range 22.8–24.3 kmc.

621.375.1.016.35 793

Multistage Amplifier Stability Design Criteria—L. G. Cripps. (*Electronic Radio Eng.*, vol. 36, pp. 454–458; December, 1959.) The stability of a cascade amplifier is considered for the two cases: where the stability factors of all the stages are equal a) before cascading, and b) after cascading. A short discussion of the results is given.

621.375.127 794

Push-Pull Amplifier Balance—(*Electronic Tech.*, vol. 37, pp. 41–43; January, 1960.) Negative voltage feedback may be applied independently to the two sides of a push-pull amplifier circuit by the insertion of an inductance and shunt resistance network in the lead to the primary center tap of the output transformer.

621.375.22:621.372.44 795

Reducing Amplifier Distortion—G. W. Holbrook. (*Electronic Tech.*, vol. 37, pp. 13–20; January, 1960.) A method is described for correcting the nonlinear distortion in tube amplifiers using metallic rectifiers as nonlinear resistances. Examples of corrected single-ended and push-pull amplifiers are given.

621.375.4 796

Some Design Considerations for High-Frequency Transistor Amplifiers—D. E. Thomas. (*Bell Syst. Tech. J.*, vol. 38, pp. 1551–1580; November, 1959.) The interaction between output and input due to internal feedback in the transistor is illustrated, and design data are developed for networks used to overcome this. Many practical amplifiers are simple and require a minimum of design effort.

621.375.9:538.569.4 797

Spin-Spin Energy Transfer and the Operation of Three-Level Masers—W. B. Mims and J. D. McGee. (Proc. IRE, vol. 47, p. 2120; December, 1959.)

621.375.9:538.569.4 798

Construction of a Strong-Field Maser-Type Type Self-Oscillator—C. Fric. (*Compt. rend. Acad. Sci., Paris*, vol. 249, pp. 80–82; July 6, 1959.) Proton spin resonance in a current of magnetically polarized water is applied in the design of a maser which operates in stable conditions without parasitic modulation. Its frequency is 29.66 mc corresponding to a field of 6980 gc. See also 2548 of 1959 (Benoit, *et al.*).

621.375.9:538.569.4 799

Operation of a Zero-Field X-Band Maser—J. E. King and R. W. Terhune. (*J. Appl. Phys.*, vol. 30, pp. 1844–1845; November, 1959.) Note on the operation of a 3-level maser amplifier at 12.3 kmc using iron-doped Al_2O_3 and only a small magnetic field for tuning.

621.375.9:538.569.4 800

Operating Characteristics of an Ammonia Beam Maser—F. S. Barnes. (Proc. IRE, vol. 47, pp. 2085–2098; December, 1959.) The simple theory is expanded to predict the angular distribution of the molecules leaving the collimator, and the effect of the focuser on the velocity distribution. Comparison with experimental data shows the importance of collisions and beam divergence. 51 references.

621.375.9:621.372.44 801

Parametric Amplification and Conversion in Propagating Circuits using Nonlinear Reactances—N. C. Chang. (Proc. IRE, vol. 47, p. 2117; December, 1959.) The case of a time-varying reactance coupling three propagating circuits is analyzed.

621.375.9:621.372.44 802

Noise Figure for a Travelling-Wave Parametric Amplifier of the Coupled-Mode Type—C. G. Shafer. (Proc. IRE, vol. 47, pp. 2117–2118; December, 1959.)

621.375.9:621.372.44:621.382.22 803

An Extremely Low-Noise 6-kmc/s Parametric Amplifier using Gallium Arsenide Point-Contact Diodes—M. Uenohara and W. M. Sharpless. (Proc. IRE, vol. 47, pp. 2114–2115; December, 1959.) Variation of excess noise temperature with diode temperature has been measured; a range of values comparable to that for a maser has been obtained. *See* also 805 below.

621.375.9:621.372.44:621.382.22 804

X-Band Parametric-Amplifier Noise Figures—B. C. De Loach and W. M. Sharpless. (Proc. IRE, vol. 47, p. 2115; December, 1959.) Two types of GaAs point-contact diode with improved gain-bandwidth properties have been examined. *See* also 803 above.

621.375.9:621.372.44:621.382.23 805

Low-Noise Parametric Amplifier using Germanium p-n Junction Diode at 6 kMc/s—M. Uenohara and A. E. Bakanowski. (Proc. IRE, vol. 47, pp. 2113–2114; December, 1959.) Experimental arrangements and results are given for noise-figure measurements at various bias voltages and temperatures.

GENERAL PHYSICS

535.62 806

Subjective Colour Tests—(*Wireless World*, vol. 66, pp. 33–34; January, 1960.) "Land colour" (3629 of 1959) is found to depend on subjective effects and picture composition to convey the color infomation to the mind of the observer. It does not, therefore, offer a practical system for color television.

537.227:539.2 807

Crystal Stability and the Theory of Ferroelectricity—W. Cochran. (*Phys. Rev. Lett.*, vol. 3, pp. 412–414; November 1, 1959.)

537.29:535.34 808

Influence of an Electric Field on an Optical Absorption Edge—W. Franz. (*Z. Naturforsch.*, vol. 13a, pp. 484–489; June, 1958.) The absorption edge displacement in a crystal with external field strength of the order of 10^5–10^6 volt/cm is interpreted.

537.311.3:536.2 809

Deviation from Matthiessen's Rule and Lattice Thermal Conductivity of Alloys—P. G. Klemens. (*Aust. J. Phys.*, vol. 12, pp. 199–202; June, 1959.) The difference in the ideal electronic thermal conductivity between an alloy and a pure metal can be estimated from the corresponding difference in the ideal electrical resistivity, using the Wiedemann-Franz law.

537.312.62 810

The Inverse Skin Effect—M. G. Haines. (*Proc. Phys. Soc.*, vol. 74, pp. 576–584; November 1, 1959.) The axial current density in an infinite cylindrical conductor is calculated as a function of radius and time. Rigid and radially expanding conductors are treated; current density distributions are obtained which sometimes have no resemblance to the normal skin effect.

537.32:536.7 811

Irreversible Thermodynamics and Kinetic Theory in the Derivation of Thermoelectric Relations—J. W. Leech. (*Canad. J. Phys.*, vol. 37, pp. 1044–1054; September, 1959.) Considerations of irreversible thermodynamics simplify the determination of thermoelectric coefficients using kinetic-theory arguments based on Boltzmann's equation. A new expression for Thomson's coefficient has been derived. Only simple models have been used but the theory is capable of extension to more complex ones.

537.56 812

The Structure of a Stream of Electrons and Ions Drifting and Diffusing in a Gas when Ionization by Collision and Molecular Attachment are Present—L. G. H. Huxley. (*Aust. J. Phys.*, vol. 12, pp. 171–183; June, 1959.)

537.56 813

Calculation of the Thermal Conductivity of an Ionic Current—H. Cabannes. (*Compt. rend. Acad. Sci., Paris*, vol. 249, pp. 47–49; July 6, 1959.) A thermal conductivity tensor for the ionic part of a plasma is derived from kinetic theory.

537.56 814

Electric Field Distributions in an Ionized Gas—M. Baranger and B. Mozer. (*Phys. Rev.*, vol. 115, pp. 521–525; August 1, 1959.) A method for improving systematically the Holtsmark distribution is described. It is then applied to the calculation of the distribution of the high-frequency component of the electric field in an ionized gas in thermal equilibrium.

537.56:538.56 815

Space-Charge Waves in Cylindrical Plasma Columns—A. W. Trivelpiece and R. W Gould. (*J. Appl. Phys.*, vol. 30, pp. 1784–1793; November, 1959.) The existence of space-charge waves in stationary plasmas of finite cross section has been demonstrated theoretically and experimentally. In addition to for ward waves, a plasma can support backward waves when there is a finite axial magnetic field. This makes possible the design of a backward-wave oscillator in which the plasma is the slow-wave circuit. Other possible applications are noted.

537.56:538.63 816

Electromotive Force in a Highly Ionized Plasma Moving Across a Magnetic Field—M. Sakantula, B. E. Clotfelter, W. B. Edwards, and R. G. Fowler. (*J. Appl. Phys.*, vol. 30, pp. 1669–1671; November, 1959.) The EMF is proportional to the flow speed. Oscillographic probe measurements of flow velocity and plasma resistance are described.

538.221 817

Statistical Mechanical Theory of a Random Ferromagnetic System—R. Brout. (*Phys. Rev.*, vol. 115, pp. 824–835; August 15, 1959.) Study of the behavior of solid solutions of paramagnetic impurities which are exchange-coupled in a nonmagnetic substrate yields a considerable amount of information about the nature of the exchange coupling and the temperature dependence of the spin system.

538.222:538.614 818

Study of the Paramagnetic Faraday Effect—J. Soutif-Guicherd. (*Ann. Télécommun.*, vol. 13, pp. 169–185 and 222–238; July/August and September/October, 1958.) From a study of propagation in a gyromagnetic medium the magnitude of the Faraday effect is determined as a function of the constant ξ of the medium. The theory is applied to rotation in paramagnetic salts, and curves are derived for the rotation angle s as a function of the applied field. A description is given of experimental apparatus, and results of measurements on Mn and Fe salts at wavelengths of 1 and 10 cm are compared with with theoretical calculations. 60 references. For an abbreviated report in English see *J. Appl. Phys.*, vol. 29, pp. 256–258; March, 1958.

538.3 819

Structure of the Electromagnetic Field—B. Bertotti. (*Phys. Rev.*, vol. 115, pp. 742–745; August 1, 1959.) A mathematical study of the structure of a curved space-time in which a source-free EM field is present.

538.3:517 820

Helical Fields—H. Poritsky.. (*J. Appl. Phys.*, vol. 30, pp. 1828–1837; November, 1959.) Simple analytic helically invariant solutions of the Laplace equation are given and combined to describe the electrostatic field of a charged helix, and the magnetic field of a helical electric current. Certain graphical flux plotting methods are outlined and illustrated, and network analogies are suggested for solving these fields.

538.3:530.145 821

Significance of Electromagnetic Potentials in the Quantum Theory—Y. Aharonov and D. Bohm. (*Phys. Rev.*, vol. 115, pp. 485–491; August 1, 1959.) Contrary to the conclusions of classical mechanics, there exist effects of potentials on charged particles, even in the region where all the fields vanish. The significance of this is discussed.

538.311 822

Microwave Magnetic Field near a Conducting Perturbation—D. S. Rodbell. (*J. Appl. Phys.*, vol. 30, pp. 1845–1846; November, 1959.) Experiments are described to show that locally intense microwave magnetic-field strengths can be obtained with low power levels by using a conductor to perturb the microwave electric field of a resonant cavity.

538.561:539.12 823

Radiation Produced by the Transit of Charged Particles near Ideally Conducting Bodies—Yu. N. Dnestrovskiĭ and D. P. Kostomarov. (*Radiotekh. Elektron.*, vol. 4, pp. 303–312; February, 1959.) Expressions are obtained for the energy and radiation spectrum. The excitation of oscillations by electrons entering a circular waveguide from an open half-space is discussed.

538.561:539.12:523.165 824

Radiation from Particles Exceeding the Velocity of Light, and Several Applications of it in Experimental Physics—P. A. Čerenkov. [*Science and Culture*, (Calcutta), vol. 25, pp. 281–286; November, 1959.] The history of the discovery and interpretation of Čerenkov radiation is outlined. The application of radiation measurements in the investigation of cosmic-ray showers is discussed.

538.566 825

Vertex-Excited Surface Waves on Both Faces of a Right-Angled Wedge—S. N. Karp and F. C. Karal, Jr. (*Commun. Pure Appl. Math.*, vol. 12, pp. 435–455; August, 1959.)

538.566:535.42]+534.26 826

Diffraction by an Infinite Slit—H. Levine. (*J. Appl. Phys.*, vol. 30, pp. 1673–1682; November, 1959.) A rigorous analysis of the problem for plane waves with special emphasis on short wavelengths and grazing incidence.

538.569.4:621.375.9 827

Construction of a Strong-Field Maser-Type Self-Oscillator—Fric. (*See* 798.)

538.691 828

On the Asymptotic Series Expansion of the Motion of a Charged Particle in Slowly Varying Fields—J. Berkowitz and C. S. Gardner. (*Commun. Pure Appl. Math.*, vol. 12, pp. 501–512; August, 1959.)

539.2:537.122 829

Self-Consistent Field Approach to the Many-Electron Problem—H. Ehrenreich and M. H. Cohen. (*Phys. Rev.*, vol. 115, pp. 786–790; August 15, 1959.) The self-consistent field method in which a many-electron system is described by a time-dependent interaction of a single electron with a self-consistent EM field is shown for many problems to be equivalent to the many-body treatment.

539.2:537.311.1 830

Electrodynamics of Charge Carriers of Negative Effective Mass in Crystals—S Rodriguez. (*Phys. Rev.*, vol. 115, pp. 821–823; August 15, 1959.) The transport properties of negative-effective-mass carriers in crystals are studied. The electrical conductivity of a sample in which the electron distribution function is weakly perturbed from its thermal equilibrium value is always positive, even in the presence of a magnetic field. Cyclotron resonance experiments in equilibrium should therefore display energy absorption.

539.2:538.569.4 831

Optical Pumping in Crystals—H. H. Theissing, P. J. Caplan, F. A. Dieter, and N. Rabbiner. (*Phys. Rev. Lett.*, vol. 3, pp. 460–462; November 15, 1959.) An estimate is made of the expected population change in the ground state of a crystal due to optical pumping.

539.2:538.569.4:621.372.413 832

The Coupling of a Spin System to a Cavity Mode—K. W. H. Stevens and B. Josephson, Jr. (*Proc. Phys. Soc.*, vol. 74, pp. 561–575; November 1, 1959.) A wave-mechanics treatment is given in which the expectation value of the z component of total spin angular momentum is determined. This problem has become important with recent developments in maser technology.

GEOPHYSICAL AND EXTRATERRESTRIAL PHENOMENA

523.152.3:621.396.96 833

The Determination of the Electron Density in Interplanetary Space—J. M. Kelso. (*J. Atmos. Terr. Phys.*, vol. 16, pp. 357–359; November, 1959.) The average electron density and the arc length of the ray path from a space vehicle to the ground can be measured by transmitting a pulse to the vehicle on one VHF frequency and receiving pulses emitted from a transponder in the vehicle on this and on a different frequency. In this way, electron densities of the order of 100 electrons/cm^3 can be estimated.

523.16 834

The Temperature required for Nuclear Reactions in Cosmical Electrical Discharges—C. E. R. Bruce. (*Nature*, vol. 184, suppl. no. 26, pp. 2004–2005 December 26, 1959.) It is probable that at a temperature of about 4×10^{80}K nuclear reactions occur freely.

523.164 835

Technical and Astronomical Measurements with the Bonn 25-m Radio Telescope—P. G. Mezger. (*Telefunken Ztg.*, vol. 31, pp. 213–225; December, 1958, and vol. 32, pp. 38–46; March, 1959. English summary.) Details are given of operational tests on the receiving installation of the Bonn University radio telescope on the Stockert [see 3845 of 1957 (Pederzani)]. Additions to the receiving equipment, and the calibration of the antenna by series of astronomical measurements and comparisons with results from other radio telescopes are also described.

523.164 836

The Positional Accuracy of the 25-m Radio Telescope of the Bonn Observatory—B. H. Grahl. (*Telefunken Ztg.*, vol. 31, pp. 226–232; December, 1958. English summary, pp. 272–273.) The tracking system and its adjustment and control are described. Details are also given of the alignment of the telescope axes and the correction of mechanical inaccuracies of the reflector structure.

523.164:551.510.535 837

Radio-Star Scintillations and Ionospheric Disturbances—T. R. Hartz. (*Canad. J. Phys.*, vol. 37. pp. 1137–1152; October, 1959.) Spread-*F* phenomena are not adequate to explain scintillations at 53 mc at Ottawa and precipitation of solar particles seems to be involved at high latitudes.

523.164:551.510.535 838

Cosmic Radio Noise Absorption on 25 Mc/s and F. Scatter—K. R. Ramanathan and R. V. Bhonsle. (*J. Geophys. Res.*, vol. 64, pp. 1635-1637; October, 1959.) A close connection is suggested between the observed anomalous enhancement of scattered VHF signals and the post-sunset increase in the attenuation of cosmic noise.

523.164.3 839

Observation of the Central Region of the Galaxy at 33.3 cm λ with the Large Radio Telescope of the G.A.O. [Principal Astronomical Observatory]—V. G. Malumyan. (*Dokl. Akad. Nauk SSSR*, vol. 129, pp. 1003–1004; December 11, 1959.) A note on radio-telescope observations of Sagittarius made in June, 1959, with a receiver of 60-mc bandwidth and antenna temperature sensitivity <1°K with a 5-second time-constant. Recordings show two brightness components with half-widths respectively 5' and 1.25°. Observations were also made at 3.2 and 9.4 cm λ.

523.164.3 840

Observation of the Sagittarius-A Radio Source at High Resoultion—Yu. N. Parilskiĭ.

Dokl. Akad. Nauk SSSR, vol. 129, pp. 1261–1263; December 21, 1959.) Description of observations carried out in April, 1959, by the Pulkovo radio telescope. Graphs show the complex structure of the source. *See* 839 above.

523.164.3 841

Neutral Hydrogen Gas in the Taurus-Orion Region observed with a Multichannel 21-cm Line Receiver—R. X. McGee and J. D. Murray. (*Aust. J. Phys.*, vol. 12, pp. 127–133; June, 1959.)

523.164.32:523.165 842

Solar Radio Bursts and Low-Energy Cosmic Rays—A. R. Thompson and A. Maxwell. (*Nature*, vol. 185, pp. 89–90; January 9, 1960.) Events following a solar flare are elucidated from a study of the relation between continuum radiation [1126 *1* of 1958 (Maxwell, *et al.*)] and the occurrence of enhanced proton flux at the earth.

523.164.32:523.755 843

On the Correlation of Solar Noise Fluctuations in Harmonically Related Bands—L. R. O. Storey. (*J. Res. Nat. Bur. Stand.*, vol. 63D, pp. 293–296; November/December, 1959.) A method is proposed for the study of the solar corona; a delayed correlation between rapid fluctuations of enhanced solar radio emission (Type II) in harmonically related frequency bands would be observed.

523.164.4 844

Occultations of the Crab Nebula by the Solar Corona in June 1957 and 1958—O. B. Slee, (*Aust. J. Phys.*, vol. 12, pp. 134–156; June, 1959.) The distribution of 85.5-mc radiation on days when the angular separation is less than 10 solar radii is not consistent with a symmetrical scattering process; better agreement is obtained by postulating the existence of scattering and regular refraction of comparable magnitude.

523.165 845

Energy Spectrum of the Heavy Nuclei in the Cosmic Radiation between 7- and 100-BeV/Nucleon—P. L. Jain, E. Lohrmann, and M. W. Teucher. (*Phys. Rev.*, vol. 115, pp. 654–659; August 1, 1959.) From observations it is concluded that a power spectrum of the form $E^{1.6}$ (where E=energy/nucleon) holds for heavy nuclei energies up to 100 bev/nucleon and for α particles up to 7 bev. With certain assumptions, the same exponent is a satisfactory value for the spectrum of α particles for energies up to 1500 bev.

523.165 846

The Onset Times of Forbush-Type Cosmic-Ray Intensity Decreases—A. G. Fenton, K. G. McCracken, D. C. Rose, and B. G. Wilson. (*Canad. J. Phys.*, vol. 37, pp. 970–982; September, 1959.)

523.165 847

A Comparison of the Cosmic-Ray Intensity at High Altitudes with the Nucleonic Component at Ground Elevation—J. E. Henkel, J. A. Lockwood, and J. H. Trainor. (*J. Geophys. Res.*, vol. 64, pp. 1427–1438; October, 1959.) Results of balloon-borne soundings with single Geiger tubes are compared with those made by a nucleonic detector on Mount Washington at 1909-meter height.

523.165 848

On the Structure of Extensive Cosmic-Ray Air Showers: the Penetrating Component—E. W. Kellermann and N. Dickinson. (*Proc. Phys. Soc.*, vol. 74, pp. 554–560; November 1, 1959.)

523.165 849

Momentum Spectrum of the Van Allen Radiation—H. Alfvén. (*Phys. Rev. Lett.*, vol. 3, pp. 459–460; November 15, 1959.) The spectrum appears to obey the same power law as cosmic radiation indicating that the Van Allen radiation may be explained by the mechanism responsible for the acceleration of cosmic radiation.

523.3 850

Absence of Craters on the Far Side of the Moon—D. B. Beard. (*Nature*, vol. 184, suppl. no. 21, p. 1631; November 21, 1959.) The reported lower incidence of craters on the far side of the moon may be explained by the effect of the earth's gravitational field on meteoric material in orbit about the sun.

523.3:551.507.362.1 851

Observations related to the Impact of Lunik II—G. Fielder. (*Nature*, vol. 185, p. 11; January 2, 1960.) A table is given of the results of a number of independent observations of the impact of Lunik II with the moon. See also 4051 of 1959 (Davies and Lovell).

523.:551.507.362.2 852

First Results Derived from the Photographs of the Moon's Far Side—N. P. Barabashov and Yu. N. Lipskiĭ. (*Dokl. Akad. Nauk SSSR*, vol. 129, pp. 1000–1002; December 11, 1959.) Photographs taken by the third soviet cosmic rocket launched October 4, 1959, are shown. During 40 minutes of camera operation, numerous photographs were taken of the moon's far side at distances 65,200 to 68,400 km from its surface.

523.5:621.396.9 853

The Temporal Variation of the Heights of Reflection Points of Meteor Trails—A. A. Weiss. (*Aust. J. Phys.*, vol. 12, pp. 116–126; June, 1959.) There is no significant seasonal variation in either the mean height or the width of the height distribution. The mean height alone shows a diurnal variation with maximum height near midnight. Both height parameters depend on the zenith angle of the apex of the earth's way.

523.5:621.396.9 854

Air Motions and the Fading, Diversity, and Aspect Sensitivity of Meteoric Echoes—L. A. Manning. (*J. Geophys. Res.*, vol. 64, pp. 1415–1425; October, 1959.) A theory is given of meteoric reflection from distorted trails. Experimental results confirm the predictions and facilitate a determination of the principal properties of the wind profile.

523.5:621.396.9 855

Meteor Radiation Distributions and the Radio-Echo Rates Observed by Forward Scatter—M. L. Meeks and J. C. James. (*J. Atmos. Terr. Phys.*, vol. 16, pp. 228–235; November, 1959.) The diurnal variations observed by forward scatter over three different paths are found to be in reasonable agreement with predictions made using a simplified model distribution based on the radar data of Hawkins (*Astrophys. J.*, vol. 61, p. 386; 1956.

523.5:621.396.9 856

Turbulence at Altitudes of 80–100 km and its Effects on Long-Duration Meteor Echoes—J. S. Greenhow and E. L. Neufeld. (*J. Atmos. Terr. Phys.*, vol. 16, pp. 384–392; November, 1959.) The characteristics of the echoes can be readily explained in terms of multiple reflections from overdense columns of ionization and are not consistent with the theory of incoherent scattering from underdense columns.

523.746.5 857

Prediction of Sunspot Numbers for Cycle 20—W. B. Chadwick. (*Nature*, vol. 184, suppl. no. 23, p. 1787; December 5, 1959.) Comment on 3282 of 1959 (Herrinck).

550.38 858

Note on Conjugate Points of Geomagnetic Field Lines for some Selected Auroral and Whistler Stations of the I. G. Y.—E. H. Vestine. (*J. Geophys. Res.*, vol. 64, pp. 1411–1414; October, 1959.) A method of deriving conjugate points of some auroral and magnetic stations of the I. G. Y.

550.385 859

Geomagnetic Oscillations at Middle Latitudes: Parts 1 and 2—E. Maple (*J. Geophys. Res.*, vol. 64, pp. 1395–1409; October, 1959.) Observations of geomagnetic fluctuations in the frequency range 1–0.005 cps, are discussed, based on measurements at Tucson, Ariz. The results favor the hypothesis of intralayer hydromagnetic resonance in the ionosphere as the source mechanism.

550.385 860

Geomagnetic Activity at Halley Bay on Disturbed Days—J. MacDowall. (*Nature*, vol. 184, pp. 1543–1545; November 14, 1959.) Diurnal variations of geomagnetic activity on disturbed days are related to auroral and ionospheric effects. An analysis of five worldwide sudden storm commencements (SSC) shows positive departures of the horizontal field before midnight and negative departures after midnight.

550.385:550.37 861

The Relation between H- and Z-Variations near the Equatorial Electrojet—C. A. Onwumechilli. (*J. Atmos. Terr. Phys.*, vol. 16, pp. 274–282; November, 1959.) Small fluctuations in H and Z are strongly correlated particularly during daylight hours. The ratio of the amplitudes of the components during these fluctuations shows a marked dirunal variation but is almost constant during the day.

550.385.26 862

Note on the Tidal Theory of the S_q Magnetic Field—R. L. Ingraham. (*J. Atmos. Terr. Phys.*, vol. 16, pp. 263–273; November, 1959.) The solar quiet day magnetic field has a diurnal component which is roughly a thousand times greater than expected on tidal theory. Possible explanations are given.

550.385.4 863

Hydromagnetic Propagation of Sudden Commencements of Magnetic Storms—W. E. Francis, M. I. Green, and A. J. Dessler. (*J. Geophys. Res.*, vol. 64, pp. 1643–1645; October, 1959.) A brief analysis of hydromagnetic propagation, which gives an expression for the transit time of waves traveling in the earth's equatorial plane.

550.389.2 864

The International Geophysical Year 1957–58—D. Brunt. (*Proc. IEE*, pt. B, vol. 106, pp. 437–443; September, 1959.) Research carried out during the I.G.Y. in different branches of geophysics is reviewed. Attention is drawn to new concepts already established and to those probably true.

551.507.362.2+629.19 865

Space Probes and Satellites—[*Engineering*, (*London*), vol. 187, pp. 615–616; May 8, 1959.] A summary of the main details of all satellite and space-vehicle launchings up to April 13, 1959.

551.507.362.2 866

Temperature Stabilization of Highly Reflecting Spherical Satellites—G. Hass, L. F. Drummeter, Jr., and M. Schach. (*J. Opt. Soc. Amer.*, vol. 49, pp. 918–924; September, 1959.)

551.507.362.2 867

A Correction Necessary for the Application of the Doppler Effect to the Measurements of

Distances to Satellites—J. M. Brito, Jr. (PROC. IRE, vol. 47, p. 2023; November, 1959.) The use of spherical-earth geometry gives a value for minimum passing range considerably lower than that obtained from plane-earth geometry.

551.507.362.2 868

The Fluctuations of the Acceleration of Satellites—H. K. Paetzold. (*J. Atmos. Terr. Phys.*, vol. 16, pp. 259–262; November, 1959.) The fluctuations are associated with changes in air density at perigee height. These density variations may be associated with changes in sunspot activity; they are, in any case, certainly due to variable heating at the perigee height.

551.507.362.2 869

A Method for Measuring Local Electron Density from an Artificial Satellite —L. R. O. Storey. (*J. Res. Nat. Bur. Stand.*, vol. 63D, pp. 325–340; November /December, 1959.) A proposal for a satellite equipped to measure the electric and magnetic fields in the radio wave set up in the neighborhood of the satellite by "whistler"-mode transmission from a ground-based VLF transmitter. From the wave impedance given by the ratio of the fields the local electron density could be deduced.

551.510.52 870

Applications of the Molecular Refractivity in Radio Meteorology —B. R. Bean and R. M. Gallet. (*J. Geophys. Res.*, vol. 64, pp. 1439–1444; October, 1959.) A discussion of the advantages of molecular refractivity as a significant parameter in studies of climatic differences and air mass characteristics.

551.510.52:621.391.812.621.1 871

Radio-Refractive-Index Climate Near the Ground—B. R. Bean and J. D. Horn. (*J. Res. Nat. Bur. Stand.*, vol. 63D, pp. 259–271; November/December, 1959.) World-wide maps of refractive index contours are given. The index varies systematically with climate, and is most accurately deduced from charts of the reduced-to-sea-level index.

551.510.52:621.391.812.621.1 872

Central Radio Propagation Laboratory Exponential Reference Atmosphere—B. R. Bean and G. D. Thayer. (*J. Res. Nat. Bur. Stand.*, vol. 63D, pp. 315–317; November/December, 1959.) A model for the variation of atmospheric refractive index with height is proposed which gives more accurate radio-ray profiles than the 4/3 earth radius treatment. A sample table of ray profiles is given.

551.510.53 873

Analytic and Experimental Electrical Conductivity between the Stratosphere and the Ionosphere—R. E. Bourdeau, E. C. Whipple, Jr, and J. F. Clark. (*J. Geophys. Res.*, vol. 64, pp. 1363–1370; October, 1959.) Results for the height range 35–80 km obtained from rocket soundings are compared with predicted values based on ion equilibrium and ionization by cosmic rays only.

551.510.535 874

Detection of an Electrical Current in the Ionosphere above Greenland—L. J. Cahill, Jr. (*J. Geophys. Res.*, vol. 64, pp. 1377–1380; October, 1959.) A description of measurements made on August 6, 1957, using a rocket-borne magnetometer. The average current density of the layer detected was about 11A/km^2.

551.510.535 875

Langmuir Probe Measurements in the Ionosphere—R. L. Boggess, L. H. Brace, and N. W. Spencer. (*J. Geophys. Res.*, vol. 64, pp. 1627–1630; October, 1959.) Measurements are described of electron temperature and positive-ion number density of the *E* layer above Fort Churchill, Manitoba, Canada, on November 30, 1958.

551.510.535 876

Note on Quiet-Day Vertical Cross-Sections of the Ionosphere along 75°W Geographic Meridian—J. W. Wright. (*J. Geophys. Res.*, vol. 64, pp. 1631–1634; October, 1959.) A discussion of results now being obtained from stations on the 75th meridian.

551.510.535 877

Gyro-Frequency in the Ionospheric Regions —S. Datta and R. N. Datta. (*Indian J. Phys.*, vol. 33, pp. 316–324; July, 1959.) Experimental results show that the magnetic fields calculated from gyro frequencies in the *E*, *F*, and F_2 regions are higher than expected. The *E*-region gyrofrequency has a marked semidiurnal variation with a minimum at midday.

551.510.535 878

An Investigation of the Ionospheric D Region—J. A. Fejer and R. W. Vice. (*J. Atmos. Terr. Phys.*, vol. 16, pp. 291–306; November, 1959.) A model of the lower ionosphere between 68 km and 85 km is obtained from the observation of weak echoes from the D region and the measurement of ionospheric wave interaction.

551.510.535 879

Some Measurements of Collision Frequency in the E Region of the Ionosphere—D. M. Schlapp. (*J. Atmos. Terr. Phys.*, vol. 16, pp. 340–343; November, 1959.) Measurements are made by observing how the deviative absorption of a radio echo varies with changes in its group path as a critical frequency is approached. Collision frequency at a fixed height seems to increase with solar activity.

551.510.535 880

E-Region Winds—W. H. Ward. (*J. Atmos. Terr. Phys.*, vol. 16, pp. 394–395; November 1959.) The suggestion that heating of the E, region by the sun is responsible for E-region winds is supported by some experimental results. See also 3259 of 1955 (Greenhow and Neufeld).

551.510.535 881

A Relation between Giant Travelling Disturbances and Sporadic-E Ionization—L. H. Heisler. (*Nature*, vol. 184, suppl. no. 23, pp. 1788–1789; December 5, 1959.) Ionosonde records for the period July 10–28, 1955, show a relation between E_s anomalies and traveling disturbances. Sequential E_s [1899 of 1951 (McNicol and Gipps)] and F_2 cusp-type anomalies [1434 of 1957 (Munro and Heisler)] are also discussed in relation to these disturbances.

551.510.535 882

Two Anomalies in the Behaviour of the F_2 Layer of the Ionosphere—S. Croom, A. Robbins, and J. O. Thomas. (*Nature*, vol. 184, suppl. no. 26, pp. 2003–2004; December 26, 1959.) Report of a study of electron-density data at a number of widely distributed observatories during equinox in a year of high sunspot activity. Results show that the "geomagnetic anomaly" described by Appleton (1337 of 1955) extends much farther from the magnetic equator as lower heights are investigated. A diurnal asymmetry also exists, with forenoon electron densities greater than corresponding afternoon ones.

551.510.535 883

Some Remarks on Motion of Ionospheric Irregularity—N. Matuura. (*Rept. Ionosphere Space Research Japan*, vol. 13, pp. 4–20; March, 1959. Discussion.) The relative motion between irregularities in electron density and their surroundings is discussed. Two treatments of the problem are considered: the surrounding ionization being assumed to be a) a hydromagnetic fluid, and b) a fully ionized gas.

551.510.535 884

The Motion of Irregularities in the Ionosphere—T. Tsuda. (*Rept. Ionosphere Space Research Japan*, vol. 13, pp. 56–61; March, 1959. Discussion.) The mean velocity of irregularities in electron density is determined using simple turbulence theory. The irregularities move with the same velocity as the winds in the E region but there is a marked difference from wind velocity in the F region.

551.510.535 885

World-Wide Measurements of Horizontal Ionospheric Drifts—T. Shimazaki. (*Rept. Ionosphere Space Research Japan*, vol. 13, pp. 21–47; March, 1959. Discussion.) A critical survey is made of radio techniques for measuring horizontal drifts. A comparison is then made of results obtained during the I.G.Y. using the closely-spaced-receiver method which discloses seasonal and latitudinal differences in the diurnal variation of drifts. Tentative explanations of these results are given.

551.510.535 886

Ionospheric Drifts at Yamagawa in Japan—K. Tsukamoto and Y. Ogata. (*Rept. Ionosphere Space Research Japan*, vol. 13, pp. 48–55; March, 1959. Discussion.) Drift speeds, diurnal variations of the drift vector, and the relation between speed and geomagnetic activity are discussed using results obtained during about one year from August, 1957.

551.510.535 887

Ionized Irregularities and Wind Motion in the Ionosphere—S. Kato. (*Rept. Ionosphere Space Research Japan*, vol. 13, pp. 62–78; March, 1959. Discussion.) The motion of irregularities in electron density are studied on the basis of a three-dimensional model. Electrodynamic effects are slight in the E region under magnetically quiet conditions but are appreciable in the F region and even in the E region for disturbed conditions at high latitudes. A general discussion on the stability and lifetime of regions of irregular electron density is given.

551.510.535 888

Horizontal Winds and Ionization Drifts in the Ionosphere—H. Maeda. (*Rept. Ionosphere Space Research Japan*, vol. 13, pp. 79–90; March, 1959. Discussion.) From a study of geomagnetic observations during the International Polar Year, 1932–1933, it is concluded that ionization drifts in the F region are due to an applied electric field and not to air movement, while in the E region the ionization drift is almost the same as the air movement.

551.510.535 889

Horizontal Drifts in the E Region at Waltair—R. R. Rao and B. R. Rao. (*Nature*, vol. 185, pp. 27–28; January 2, 1960.) Results of an analysis of data obtained over a two-year period. A 24-hourly east-west component predominates.

551.510.535 890

Study of "Winds" in the F Region of the Ionosphere during the Unusual Days in the I.G.Y. Calendar—R. N. Singh and S. R. Khastgir. (*J. Atmos. Terr. Phys.*, vol. 16, pp. 376–383; November, 1959.) Fading records were taken at 3.8–4.2 mc on three spaced receivers at Banaras. The experimental results are described and the fading records discussed with reference to the random and steady movement of irregularities.

551.510.535:523.5:621.396.96 891

A Theory for determining Upper-Atmos-

phere Winds from Radio Observations on Meteor Trails—G. V. Groves. (*J. Atmos. Terr. Phys.*, vol. 16, pp. 344–356; November, 1959.)

551.510.535:523.78 892

The Effects of a Solar Eclipse on a Stratified Ionosphere—J. A. Gledhill. (*J. Atmos. Terr. Phys.*, vol. 16, pp. 360–366; November, 1959.) The form of the isoelectronic surfaces in a three-layer ionosphere during an eclipse have been calculated. Tilts in these surfaces may lead to difficulties in the interpretation of ionograms.

551.510.535:523.78 893

The Behaviour of the Ionosphere over Cape Town and Johannesburg during the Annular Solar Eclipse of 25 December 1954—J. A. Gledhill. (*J. Atmos. Terr. Phys.*, vol. 16, pp. 367–375; November, 1959.) It was not possible to explain the ionospheric changes at Cape Town, Johannesburg and Grahamstown in terms of a single solar brightness model. Oblique reflections may have affected the ionograms. There is some evidence that $\alpha'E = 4 \times 10^{-8} cm^3 second^{-1}$.

551.510.535:621.391.812.63 894

The Frequency Dependence of Ionospheric Absorption—K. Bibl, A. Paul, and K. Rawer. (*J. Atmos. Terr. Phys.*, vol. 16, pp. 324–339; November, 1959. In German.) The total absorption was formerly expressed as a function of nondeviative D-layer plus deviative E-layer absorption [985 of 1952 (Bibl and Rawer)]. The expression has been modified to include the effect of a thin E_s layer. Experimental data are discussed in the light of the new theory.

551.510.535:621.391.812.63 895

The Absorption of Short Radio Waves in the D, E and F Regions of the Ionosphere—J. D. Whitehead. (*J. Atmos. Terr. Phys.*, vol. 16, pp. 283–290; November, 1959.) Values of noon absorption at Slough from 1947 to 1953 have been analyzed. The electron collision frequencies for the E and F regions have been calculated and the variations of D-region absorption with sunspot number examined. The significance of the results is discussed.

551.510.535:621.391.812.63 896

The Use of Full-Wave Solutions in the Interpretation of Ionospheric Absorption Measurements—J. A. Fejer and R. W. Vice. (*J. Atmos. Terr. Phys.*, vol. 16, pp. 307–317; November, 1959.) A full-wave correction is given which can be made to the usual Appleton-Hartree absorption calculation. Examples show that for a frequency of 2 mc this correction cannot be neglected.

551.510.535:621.396.96:523.3 897

Measurements of Ionospheric Electron Content by the Lunar Radio Technique—S. J. Bauer and F. B. Daniels. (*J. Geophys. Res.*, vol. 64, pp. 1371–1376; October, 1959.) Measurements of the Faraday rotation of lunar radio echoes at 151 mc are used to determine the time variation in the total ionospheric electron content. Absolute values of electron content are derived from data on the electron content below the F_2 peak computed from vertical-incidence experiments.

551.593 898

Excitation Mechanisms of the Oxygen 5577 Emission in the Upper Atmosphere—E. Tandberg-Hanssen and F. E. Roach. (*J. Res. Nat. Bur. Stand.*, vol. 63D, pp. 319–324; November/December, 1959.) Photochemical reactions affected by mass motions, and direct excitation due to mass motions are examined.

551.594.5+551.593 899

Auroral and Nightglow Observations at Ås, Norway—G. Kvifte. (*J. Atmos. Terr. Phys.*, vol. 16, pp. 252–258; November, 1959.) More precise wavelength measurements are given for bands of the Meinel OH system in the nightglow.

551.594.5 900

Photometric Observations of Subvisual Red Auroral Arcs at Middle Latitudes—R. A. Duncan. (*Aust. J. Phys.*, vol. 12, pp. 197–198; June, 1959.) The arcs have been observed on the night following a bright visual aurora at a time when the magnetic disturbance index had fallen to five or less.

551.594.5 901

The Southern Auroral Zone in Geomagnetic Longitude Sector 20°E—S. Evans and G. M. Thomas. (*J. Geophys. Res.*, vol. 64, pp. 1381–1388; October, 1959.) Visual auroral observations at Antartic bases are tabulated to show the variation of the frequency of aurora occurrences with geomagnetic latitude between 63° and 79°.

551.594.5 902

Antartic Auroral Observations, Ellsworth Station, 1957—J. M. Malville. (*J. Geophys. Res.*, vol. 64, pp. 1389–1393; October, 1959.) A summary of auroral observations made during the antarctic winter of 1957. Evidence is obtained of a spiraling zone of maximum auroral activity.

551.594.5 903

Spectroscopic Observations of the Great Aurora of 10 February 1958: Parts 1 and 2—K. C. Clark and A. E. Belon. (*J. Atmos. Terr. Phys.*, vol. 16, pp. 205–227; November, 1959.) Spectrograms show an enhancement of vibrational excitation in the $B(F^2\Sigma_u{}^+)$ state of $N_2{}^+$ which can be attributed to a charge exchange process in a strong proton shower. These spectrograms also show a large number of atomic lines seldom seen, most of which are due to *OI* and N *II* transitions.

551.594.5 904

A Monochromatic Low-Latitude Aurora—F. E. Roach and E. Marovich. (*J. Res. Nat. Bur. Stand.*, vol. 63D, pp. 297–301; November/December, 1959.) A particular monochromatic auroral arc (6300Å) which occurred over Colorado, September 29–30, 1957, is described. It seems to have been a continuation of a similar one observed in France.

551.594.6 905

Telluric Origin of the Whistler Medium—F. S. Johnson. (*Nature*, vol. 184, suppl. no. 23, pp. 1787–1788; December 5, 1959.) Arguments are presented to show that the medium cannot be of solar or interplanetary origin and a mechanism is suggested for a telluric origin.

551.594.6 906

Effect of Latitude on the Diurnal Maximum of "Dawn Chorus"—J. H. Pope. (*Nature*, vol. 185, pp. 87–88; January 9, 1960.) Observations of the local time of diurnal maximum have been made at 16 stations. Analysis based on an eccentric dipole field is useful when considering "dawn chorus" theories.

521.030:537.5 907

Cosmic Electrodynamics. (Book Review)—J. W. Dungey, Publishers: University Press, Cambridge, 183 pp.; 1958. (*Nature*, vol. 184, pp. 1672–1673; November 28, 1959.) This book, bearing a similar title to that by Alfvén (see 2777 of 1950), indicates the progress and consolidation achieved in the field during the intervening decade.

LOCATION AND AIDS TO NAVIGATION

621.396.96 908

Optical Simulation of Radar Resolution—R. D. Rawcliffe, W. W. Lichtenberger, and H. V. Krone. (*J. Opt. Soc. Amer.*, vol. 49, pp. 887–890; September, 1959.) An optical simulator has been constructed in which the high resolution of an aerial photograph is degraded by known amounts in order to determine the radar resolution required to achieve a given target detectability.

621.396.96:621.396.934 909

Low-Cost Active Radar for Miss-Distance Data—W. H. Doty. (*Electronics*, vol. 32, pp. 91–93; November 20, 1959.) Frequency-sweep radar located within the target gives a direct indication of the miss distance.

621.396.965.4:534.88 910

Underwater Echo-Ranging with Electronic Sector Scanning: Sea Trials on *R.R.S. Discovery II*—Tucker, Welsby, Kay, Tucker, Stubbs, and Henderson. (*See* 745.)

621.396.967 911

The Line Elements between Transmitter and Aerial of a Radar Installation and their their Influence on Transmitter Frequency Stability—H. Schwindling. (*Telefunken Ztg*, vol. 31, pp. 242–253; December, 1958. English summary, pp. 273–274.) An airport surveillance radar installation is examined with regard to stability conditions governed by the "long-line" effect (3653 of 1958). The maintenance of stability by means of phase shifters can only be carried out by referring to the frequency spectrum of the transmitted pulses.

MATERIALS AND SUBSIDIARY TECHNIQUES

535.215 912

The Theory of Glow Curves—K. W. Böer, S. Oberländer, and J. Voight. (*Z. Naturforsch.*, vol. 13a, pp. 544–547; July, 1958.) The analysis of trapping-center distribution on the basis of glow curves and allowing for retrapping is considered. See also 3321 of 1959.

535.215 913

Gain-Bandwidth Product of Photoconductors—R. W. Redington. (*Phys. Rev.*, vol. 115, pp. 894–896; August 15, 1959.) Extension of earlier treatment (1914 of 1958) to include an arbitrary distribution of impurity levels. Results show the reciprocal of the relaxation time to be an upper limit for the gain-bandwidth product of a photoconductor with space-charge-limited dark current.

535.215:546.48'221 914

Dislocations in CdS Crystals and their Significance in Photoconductivity—E. Votava. (*Z. Naturforsch.*, vol. 13a, pp. 542–544; July, 1958. plate.) Methods of growing crystals with pronounced dislocations and of making these visible are discussed. Experiments seem to confirm that dislocations may reduce the electron lifetime.

535.215:546.48'221 915

The Electrical Behaviour of CdS Single Crystals with Voltage Pulses in the Breakdown Region—K. W. Böer, J. Dziesiaty, and U. Kümmel. (*Z. Naturforsch.*, vol. 13a, pp. 560–562; July, 1958.) Crystal current is plotted as a function of pulse width, amplitude and repetition frequency and comparisons are made with dc measurements at breakdown field strength. [see also 2749 of 1958 (Böer and Kümmel)].

535.215:546.863'221 916

Cathodoconductivity of Antimony Sulphide—Ya. A. Oksman and G. P. Tikhomirov (*Radiotekh. Elektron.*, vol. 4, pp. 344–346 February, 1959.) Investigation of the possibility of increasing the conductivity of thin dielectric and semiconductor films by electron bombardment for the purpose of amplifying the photoelectron emission current. The limiting values of the gains which can be obtained using these films at room temperature are determined. See 2458 of 1957 (Oksman).

535.37:546.47’221 917

Optical Properties of Activated and Unactivated Hexagonal ZnS Single Crystals—S. P. Keller and G. D. Pettit. (*Phys. Rev.*, vol. 115, pp. 526–536; August 1, 1959.) Further measurements on the polarization effects in the transmission spectrum of unactivated ZnS show that theoretical prediction holds except in the region 290–325 mμλ. The wavelength dependence and the polarization of the excitation and fluorescence spectra of the activated and unactivated crystals were measured at room temperature and at 77°K.

535.376 918

Energy Limit for Electroenhancement and Electroextinction Effects—G. Destriau. (*Compt. rend. Acad. Sci., Paris*, vol. 249, pp. 245–247; July 15, 1959.) The sensitivity of luminescent compounds of the CdZnS-Mn, *X* type under electron bombardment is enhanced by X-ray and reduced by ultraviolet-ray excitation. Extrapolation of experimental curves indicates that with an activation energy below 5000 ev no electroenhancement occurs.

535.376 919

New Effect of Sensitization to the Action of X Rays, by means of Infrared, in Luminescent Products of the Type CdZnS-Mn, *X*—F. Pingault. (*Compt. rend. Acad. Sci., Paris*, vol. 249, pp. 248–250; July 15, 1959.) Infrared radiation produces an enhancement effect similar to that described by Destriau (*see, e.g.* 918 above). The analogy between the action of an applied electric field and infrared irradiation is stressed.

535.376:546.48’221 920

Some Effects of Low Fields on Luminescence of CdS—C. E. Bleil and D. D. Snyder. (*J. Appl. Phys.*, vol. 30, pp. 1699–1702; November, 1959.) Experimental results are given for the shift of cathodoluminescence peaks with applied field and for the dependence of conductivity on voltage and irradiation. An explanation is suggested.

537.227 921

Asymmetric Hysteresis Loops and the Pyroelectric Effect in Triglycine Sulphate—A. Savage and R. C. Miller. (*J. Appl. Phys.*, vol. 30, pp. 1646–1648; November, 1959.) The apparent asymmetry, as disclosed by pyroelectric measurements, is shown to be due to electrode edge effects.

537.227 922

Domain Processes in Lead Titanate Zirconate and Barium Titanate Ceramics—D. Berlincourt and H. H. A. Krueger. (*J. Appl. Phys.*, vol. 30, pp. 1804–1810; November, 1959.) An experimental investigation of domain reorientation during poling, and domain switching processes under high mechanical or electric stress.

537.227:546.431’824–31 923

On the Dependence of the Switching Time of Barium Titanate Crystals on their Thickness—M. E. Drougard and R. Landauer. (*J. Appl. Phys.*, vol. 30, pp. 1663–1668; November, 1959.) Analysis of domain motion and field calculations show that the dependence of switching rate on thickness is explained by a monomolecular surface layer having an irreversible polarization and a low dielectric constant. Implications of this in explaining the switching mechanism are discussed.

537.311.31:538.63 924

Magnetoresistance of Copper—J. de Launay, R. L. Dolecek, and R. T. Webber. (*J. Phys. Chem. Solids*, vol. 11, pp. 37–42; September, 1959.) Report and discussion of measurements at 297°, 78° and 4.2°K in transverse and in longitudinal fields up to 100 kg.

537.311.33 925

Electric Conduction in Semiconductors—H. Fröhlich and G. L. Sewell. (*Proc. Phys. Soc.*, vol. 74, pp. 643–647; November 1, 1959.) In semiconductors with low mobility the usual theory of conduction is invalid. An expression for mobility is derived which should apply in such cases under certain conditions.

537.311.33 926

Volume and Surface Recombination of Injected Carriers in Cylindrical Semiconductor Ingots—J. P. McKelvey. (IRE Trans. on Electron Devices, vol. ED-5, pp. 260–264; October, 1958. Abstract, Proc. IRE, vol. 47, p. 495; March, 1959.)

537.311.33 927

Metal-to-Semiconductor Contacts: Injection or Extraction for Either Direction of Current Flow—N. J. Harrick. (*Phys. Rev.*, vol. 115, pp. 876–882; August 15, 1959.) Infrared radiation is used to measure the current-density /added-carrier-density characteristics. The nature of the semiconducting surface rather than the metal is the major factor controlling the contact characteristics. Two unusual classes of results are described.

537.311.33 928

Compound Semiconductors—D. A. Wright. (*Electronic Engrg.*, vol. 31, pp. 659–665; November, 1959.) After a general description of some factors influencing performance, applications of individual binary and ternary compounds are considered with reference to tabulated data on their properties. The optimum requirements for thermoelectric refrigeration are noted.

537.311.33 929

On the Study of the Semiconductor Properties of Chalcogenides of Aluminium, Gallium and Indium—E. Kauer and A. Rabenau. (*Z. Naturforsch.*, vol. 13a, pp. 531–536; July, 1958.) Optical measurements confirm that all chalcogenides of Al, Ga and In of the type $A_2^{III}B_3^{VI}$ have semiconductor properties. Band gaps and their temperature dependence are given and compared with the results of other authors.

537.311.33:061.3 930

1958 International Conference on Semiconductors—(*J. Phys. Chem. Solids*, vol. 8, pp. 1–552; January, 1959.) The text is given of papers presented at the conference held in Rochester, N.Y. August 18–22, 1958.

537.311.33:534.2–8 931

The Conductivity of Semiconductors in an Ultrasonic Field—V. A. Zhuravlev and M. I. Kozak. (*Zh. Eksp. Teor. Fiz.*, vol. 36, pp. 343–344; January, 1959.) Measurements have been made on Se, CdS, PbS, Cu_2O, SnO_2 and Ge semiconductors in a 600-kc field of intensity 10 watts/cm^2. Conductivity changes occurred in all cases and are attributed to thermal effects of the irradiation.

537.311.33:538.63 932

The Influence of the Geometry on the Transverse Magnetoresistance Effect in Rectangular Semiconductor Plates—H. J. Lippmann and F. Kuhrt. (*Z. Naturforsch.*, vol. 13a, pp. 462–474; June, 1956.) The resistance effect controlled by the geometry of the specimen is calculated for small and large Hall angles. The theoretical results obtained accord with measurements made on InSb specimens by Weiss and Welker (143 of 1955).

537.311.33:538.632 933

The Influence of the Geometry on the Hall Effect in Rectangular Semiconductor Plates—H. J. Lippman and F. Kuhrt. (*Z. Naturforsch.*, vol. 13a, pp. 474–483; June, 1958.) *See* also 932 above.

537.311.33:539.12.04 934

Temperature-Dependent Defect Production in Bombardment of Semiconductors—G. K. Wertheim. (*Phys. Rev.*, vol. 115, pp. 568–569; August 1, 1959.) The decreased defect density observed after low-temperature bombardment may be due to the production of a metastable vacancy—interstitial pair which may either anneal or form the defect. A temperature dependence in the production rate arises if these two competing processes have different activation energies.

537.311.33:546.26–1 935

Electrical Resistivity Changes Observed in a Semiconducting Diamond after Heat Treatment—R. E. Mutch and F. A. Raal. (*Nature*, vol. 184, suppl. no. 24, pp. 1857–1858; December 12, 1959.) Resistivity measurements on a diamond slab consisting of a blue and a white portion show that both portions are semiconducting to different degrees and are separated by a well-defined boundary. The reduction in donor concentration in both portions on heating appears to be consistent with a bimolecular annealing process, the white portion, with more donor centers, showing a greater change in resistivity.

531.311.33:546.28 936

Infrared Spectrum and Carrier Mobility in the Intrinsic-Conduction Range of Silicon—F. R. Kessler and J. Schnell. (*Z. Naturforsch.*, vol. 13a, pp. 458–461; June, 1958.) Measurements of conductivity and infrared absorption between 1.0 and 3.5μ were made in the temperature range 300°–1000 °K on single-crystal *i*-type Si. The carrier density obtained is in agreement with that derived from Hall-effect measurements by other authors.

537.311.33:546.28 937

Deep Energy Levels in Silicon—H. Irmler. (*Z. Naturforsch.*, vol. 13a, pp. 557–559; July, 1958.) The recombination-center and acceptor energy levels were determined from measurements on pure Si and Si specimens doped with Cu, Ag or Co.

537.311.33:546.28 938

The Control of Resistivity in Pulled Silicon Crystals—A. Trainor and P. T. Harris. (*Proc. Phys. Soc.*, vol. 74, pp. 669–670; November 1, 1959.) This is achieved by pulling with a reduced gas pressure to permit evaporation of the impurity.

537.311.33:546.28 939

Diffusion of Oxygen in Silicon—R. A. Logan and A. J. Peters. (*J. Appl. Phys.*, vol. 30, pp. 1627–1630; November, 1959.) By studying the process of the donor fomation by heat treatment in crystals of known oxygen concentration, the solubility and diffusivity of oxygen in Si in the temperature range 1250°–1400°C have been determined.

537.311.33:546.28 940

Infrared Studies of Birefringence in Silicon—S. R. Lederhandler. (*J. Appl. Phys.*, vol. 30, pp. 1631–1638; November, 1959.) Techniques are described for observing and measuring permanent and elastic strains.

537.311.33:546.289 941

Zeeman Effect on Light due to Intrinsic Recombination in Germanium—C. Benoit à la Guillaume and O. Parodi. (*J. Electronics Control*, vol. 6, pp. 356–358; April, 1959. In French.) Observations of the Zeeman effect on recombination radiation in As-doped Ge show the energy shift in a field of 40,000 oersteds to be about 4×10^{-4} ev and confirm the hypothesis that this radiation is due to exciton annihilation. See 3369 of 1959 (Gosnet, *et al.*).

537.311.33:546.289 942

Light Emission and Noise Studies of Individual Microplasmas in Silicon p-n Junctions—A. G. Chynoweth and K. G. McKay. (*J. Appl. Phys.*, vol. 30, pp. 1811–1813; November, 1959.) "At low currents in the prebreakdown region of broad-area diffused silicon p-n junctions in which the breakdown is by an avalanche mechanism, only a few light-emitting microplasmas are present. These appear in succession as the current is increased and the appearance of each spot is accompanied by its own set of characteristic microplasma current pulses. It is found also that effectively all the emitted light arises at these microplasmas and that they carry, essentially, all of the breakdown current. The light intensity of an individual microplasma is roughly proportional to the current flowing through it."

537.311.33:546.289 943

Visible Light from a Germanium Reverse-Biased p-n Junction—J. T. Nelson and J. C. Irvin. (*J. Appl. Phys.*, vol. 30, p. 1847; November, 1959.) A phenomenon similar to that observed in Si [see, *e.g.*, 3514 of 1958 (Cheynoweth and Pearson)] is described.

537.311.33:546.289 944

Observation of Direct Tunnelling in Germanium—J. V. Morgan and E. O. Kane. (*Phys. Rev. Lett.*, vol. 3, pp. 466–468; November 15, 1959.) The transition from "indirect" to "direct" tunnelling has been observed experimentally at 77°K. Calculations are compared with experimental data.

537.311.33:546.289:534.2–8 945

Temperature Dependence of Fractional Velocity Changes in a Germanium Single Crystal—F. Stein, N. G. Einspruch, and R. Truell. (*J. Appl. Phys.*, vol. 30, pp. 1756–1758; November, 1959.) Report of interferometer measurements of elastic constants for compressional-wave propagation in the frequency range 30–170 mc.

537.311.33:546.289:535.514.2–15 946

Polarization of Infrared Radiation by Reflection from Germanium Surfaces—D. F. Edwards and M. J. Bruemmer. (*J. Opt. Soc. Amer.*, vol. 49, pp. 860–861; September, 1959.) A Ge surface is an efficient infrared polarizer over a wide range of wavelengths.

537.311.33:546.289:538.63 947

Nernst and Ettingshausen Effect in Germanium between 300 and 750°K—H. Mette, W. W. Gärtner and C. Loscoe. (*Phys. Rev.*, vol. 115, pp. 537–542; August 1, 1959.) Measurements have been made between 300° and 750°K of a) the two effects in single crystals of different conductivity type and with various impurity densities, in magnetic fields of 9000 G; b) the Nernst effect of 2100 G. Results are compared with theory.

537.311.33:546.289:539.23 948

Electrical Conductivity of Amorphous Vapour-Deposited Germanium Films—L. Reimer. (*Z. Naturforsch.*, vol. 13a, pp. 536–541; July, 1958.) The temperature dependance of resistivity was measured in vacuum in the temperature range 20°–400°C. Comparisons are made with the properties of crystalline films.

537.311.33:546.48'19 949

Cyclotron Resonance in $CdAs_2$—M. J. Stevenson. (*Phys. Rev. Lett.*, vol. 3, pp. 464–466; November 15, 1959.)

537.311.33:546.682'86 950

Thermal Conductivity of Indium Antimonide at Low Temperatures—E. V. Mielczarek and H. P. R. Frederikse. (*Phys. Rev.*, vol. 115, pp. 888–891; August 15, 1959.) Umklapp, isotope and boundary scattering contributions to thermal resistivity were calculated theoretically and subtracted from the measured value of thermal resistivity. The number of point impurities subsequently deduced agrees with that given by electrical measurements.

537.311.33:546.682'86 951

The Energy-Dependence of Electron Mass in Indium Antimonide determined from Measurements of the Infrared Faraday Effect—S. D. Smith, T. S. Moss, and K. W. Taylor. (*J. Phys. Chem. Solids*, vol. 11, pp. 131–139; September, 1959.) Values of dE/dK as a function of k_F for the conduction band of InSb, where k_F is the wave vector at the Fermi surface, have been calculated from the Faraday rotation due to free electrons. Results are in agreement with the band structure calculated by Kane (3156 of 1958).

537.311.33:546.682'86 952

Plastic Deformation of InSb by Uniaxial Compression—J. J. Duga, R. K. Willardson, and A. C. Beer. (*J. Appl. Phys.*, vol. 30, pp. 1798-1803; November, 1959.) Plastic deformation by unixaial compression was found to decrease electron mobility and magnetoresistance but to have no effect on the Hall coefficient.

537.311.33:546.873'241 953

The Magnetic Susceptibility of Bismuth Telluride—R. Mansfield. (*Proc. Phys. Soc.*, vol. 74, pp. 599–603; November 1, 1959.) The susceptibility has been measured over the temperature range 100°-600°K; the magnitude of the contributions to the susceptibility from various sources is discussed.

537.311.33:548.0 954

The Effect of Pressure on Zinc Blende and Wurtzite Structures—A. L. Edwards, T. E. Slykhouse, and H. G. Drickamer. (*J. Phys. Chem. Solids*, vol. 11, pp. 140–148; September, 1959.)

537.311.33:621.382 955

Temperature Dependence and Lifetime in Semiconductor Junctions—D. A. Jenny and J. J. Wysocki. (*J. Appl. Phys.*, vol. 30, pp. pp. 1692–1698; November, 1959.) The temperature dependence of p-n-junction current can be held to a minimum over a given temperature range by using material with a minority-carrier lifetime below a certain value. Calculations applied to GaAs show that an optimum lifetime should be attainable in practice by controlled doping with recombination-center impurities. The upper operating-temperature limit of junction devices is calculated for Ge, Si, InP and GaAs.

537.311.33:621.391.822 956

Load-Dependent Noise in Oxide Semiconductors at Low Frequencies—K. Leberwurst. (*NachrTech.*, vol. 8, pp. 568–580; December, 1958.) The changes of noise characteristics with temperature and oxygen pressure are investigated for a number of sintered oxide semiconductors. From consideration of the mechanism of chemisorption a model is developed for a polycrystalline oxide semiconductor which allows for different types of noise to originate in the interior and at the boundary of unit cells making up the substance. Results of measurements are discussed with reference to an equivalent circuit based on the model.

537.312.8 957

Influence of Collective Effects on the Magnetoresistance of Metals—R. A. Coldwell-Horsfall and D. ter. Haar. (*Phys. Rev.*, vol. 115, pp. 891–893; August 15, 1959.) Two methods are used to investigate the influence of the correlations between carriers on the magnetoresistance β. The change in β in both a one-band and a two-band model is considered.

537.533 958

On the Question of Electron Emission of Nickel in the Curie Region—F. Fraunberger and A. Kellerer. (*Z. Phys.*, vol. 154, pp. 419–422; April 7, 1959.) Electron emission and, in particular, exo-electron emission of a Ni specimen was investigated to discover a possible anomaly in the Curie region. No anomaly was found.

537.533:546.431 959

Effect of Oxygen on the Work Function of Barium—P. A. Anderson and A. L. Hunt. (*Phys. Rev.*, vol. 115, pp. 550–552; August 1, 1959.) The effect is measured for various exposures to oxygen.

537.533:546.59 960

Work Function of Gold—P. A. Anderson. (*Phys. Rev.*, vol. 115, pp. 535–554; August 1, 1959.) The measured value of contact difference of potential Au-Ba is found to be 2.31 ±0.02 volts and the work function of Au 4.83±0.02 ev.

537.533:546.621 961

Electron Emission from Plastically Strained Aluminum—W. D. Von Voss and F. R. Brotzen. (*J. Appl. Phys.*, vol. 30, pp. 1639–1645; November, 1959.) An experimental investigation is made of the effect of mechanical variables on emission, both during and after straining. A model is proposed correlating these in terms of the formation of point discontinuities in the surface oxide layer and this is compared with the experimental results.

538.214:546.31 962

Magnetic Susceptibility of Alkali Elements—K. Venkateswarlu and S. Sriraman. (*Z. Naturforsch.*, vol. 13a, pp. 451–458; June, 1958. In English.)

Part 1: Sodium and Potassium (pp. 451–455).

Part 2: Liquid Alloys of Sodium and Potassium (pp. 455–458).

538.22:537.311.31 963

Magnetic Susceptibility and Electrical Resistivity of Au-Mn Alloys—A. Giansoldati, J. O. Linde, and G. Borelius. (*J. Phys. Chem., Solids*, vol. 11, pp. 46–54; September, 1959) Report of measurements on alloys containing 10–75 atomic per cent Mn.

538.221 946

The Magnetic Law of Approach in Plastically Deformed Nickel and Nickel-Cobalt Single Crystals—H. Kronmüller. (*Z. Phys.*, vol. 154, pp. 574–600; April 21, 1959.) Experimental investigation of the influence of plastic deformation at room temperature and at −183° C on the approach to ferromagnetic saturation.

538.221 965

Magnetic Viscosity in Iron due to Carbon Atoms Anchored in Dislocations—G. Biorci, A. Ferro, and G. Montalenti. (*J. Appl. Phys.*, vol. 30, pp. 1732–1735; November, 1959.)

538.221:539.234:537.312.8 966

The Determination of the Curie Temperature of Thin Films by means of the Ferromagnetic Resistance Variation—W. Hellenthal. (*Z. Naturforsch.*, vol. 13a, pp. 566–567; July, 1958.) The dependance of Curie temperature on film thickness is plotted for Ni films. See 1944 of 1959.

538.221:621.318.134 967

The Influence of the Valency States of Cations on Electrical Conductivity of Mg-Mr Ferrite—S. Krupička and Závěta. (*J. Electronics Control*, vol. 6, pp. 333–336; April, 1959.) The resistivity of iron-deficient Mg ferrite is low, owing to the presence of Fe^{2+} ions, but can be greatly increased by the addition of Mn. This is attributed to the formation of stable Mn^{4+}-Fe^{2+} pairs, preventing the Fe^{2+} ions taking part in the conduction process.

538.221:621.318.134 968

Evidence for Triangular Moment Arrangements in MO. Mn_2O_3—I. S. Jacobs. (*J. Phys. Chem. Solids*, vol. 11, pp. 1–11; September, 1959.) A consequence of the triangular arrangement of moments suggested by Yafet and Kittel (3414 of 1952) is that at field strengths higher than those required for ferrimagnetic domain alignment, there should be a linear increase in net magnetization with field. Measurements on several spinel-type compounds show this differential susceptibility.

538.221:621.318.134 969

The Magnetocrystalline Anisotropy of Cobalt-Substituted Manganese Ferrite—R. F. Pearson. (*Proc. Phys. Soc.*, vol. 74, pp. 505–512; November 1, 1959.) The anisotropy due to Co ions in Mr ferrite varies linearly with Co concentration up to 25 per cent; the variation is not as great as in magnetite or as would be expected from Co ferrite values.

538.221:621.318.134 970

Paramagnetic Resonance of Yb^{3+} in Yttrium Gallium Garnet—D. Boakes, G. Garton, D. Ryan, and W. P. Wolf. (*Proc. Phys. Soc.*, vol. 74, pp. 663–665; November 1, 1959.)

538.221:621.318.134 971

Magnetic Properties of Rare Earth Ions in Garnets—W. P. Wolf. (*Proc. Phys. Soc.*, vol. 74, pp. 665–667; November 1, 1959.) *See* also 970 above.

538.221:621.318.134:538.566 972

Faraday Effect in Various Small Ferrite Rods—F. Picherit. (*Compt. rend. Acad. Sci., Paris*, vol. 249, pp. 69–70; July 6, 1959.) The polarimetric analyzer described in 3574 of 1958 has been applied to the study of the Faraday effect in 4B ferrite rods of diameter down to 1.6 mm.

538.221:621.318.134:538.569.4 973

Magnetic Resonance of Ferrites at the Compensation Temperature—J. Paulevé. (*Ann. Télécommun.*, vol. 13, pp. 311–324; November/December, 1958. and vol. 14, pp. 2–20; January/February, 1959.) A study of ferrimagnetic resonance theory at temperatures below the Curie point supported by measurements on Li chrome ferrites and Gd and Er garnets. 43 references.

538.221:621.318.134:538.569.4 974

The Influence of Conducting Surfaces on the Gyromagnetic Resonance of Ferrite Bodies—W. Haken. (*Arch. elekt. Übertragung*, vol. 12, pp. 562–566; December, 1958.) The calculation of demagnetizing factors by magnetostatic methods must be modified if conducting surfaces are present. Using a mirror-image principle the demagnetizing factors are calculated for magnetized ferrite strips in rectangular waveguides; measurement results confirm the analysis.

538.222:538.569.4 975

Optical Detection of Paramagnetic Resonance Saturation in Ruby—I. Wieder. (*Phys. Rev. Lett.*, vol. 3, pp. 468–470; November 15, 1959.) Description of experimental measurements.

538.632:546.87:539.23 976

Hall Effect of Bismuth Films Condensed by Quenching—W. Buckel. (*Z. Phys.*, vol. 154, pp. 474–485; April 7, 1959.)

538.652 977

Measurement of the Linear Magnetostriction of Hard-Worked Nickel—H. E. Stauss. (*J. Appl. Phys.*, vol. 30, pp. 1648–1650; November, 1959.)

539.2:539.12.04 978

The Effects of Nuclear Radiation on Materials—T. P. Flanagan. (*J. Electronics Control*, vol. 6, pp. 337–346; April, 1959.) The effects of gamma and neutron radiation are described. Magnetic materials and thermocouples are included.

621.315.612.015.5 979

Dielectric Breakdown of Porous Ceramics—R. Gerson and T. C. Marshall. (*J. Appl. Phys.*, vol. 30, pp. 1650–1653; November, 1959.) The measured dielectric strength in porous materials is a function of porosity, void size, and of the dimensions of the test specimen.

621.315.615.015.5 980

Conduction Currents in Liquid *n*-Hexane under Microsecond Pulse Conditions—A. H. Sharbaugh and P. K. Watson. (*Nature*, vol. 184, suppl. no. 26, pp. 2006–2007; December 26, 1959.) No evidence for electron multiplication was obtained at fields below 1.25 mv/cm. At fields in the vicinity of breakdown, large values of current density were measured which may lead to local vaporization and the formation of bubbles with subsequent breakdown of the liquid dielectric.

621.315.616.9:621.3.048 981

An Alternative Method for Comparing the Electrical Properties of Epoxy Casting Resins—D. A. Thompson. (*Electronic Engrg.*, vol. 31, pp. 686–687; November, 1959.)

669.21/.22:621.382.3.032.27 982

Investigations on some Noble-Metal Alloys used in Semiconductor Techniques—K. Müller and W. Merl. (*Elektrotech. Z., Edn A*, vol. 80, pp. 515–518; August 1, 1959.) Physical and mechanical properties are tabulated of various alloys of Ag and Au with group-III and group-V elements suitable as contact materials for semiconductor devices, and curves of specific resistance as a function of alloy composition are given.

MEASUREMENTS AND TEST GEAR

529.786+621.3.018.41 (083.7) 983

The Determination of Time and Frequency—(*Tech. Mitt. PTT*, vol. 37, pp. 1–32; January 1, 1959.) The text is given of the following papers presented at a meeting of the Swiss national committee of URSI at Neuchâtel, 1958.

a) **The Scientific Importance of Atomic Frequency Standards**—J. Rossel (pp. 2–6. In French).

b) **The Atomic Clocks**—J. Bonanomi (pp. 6–9).

c) **The Technique of the Atomic Determination of Frequency and Time**—J. De Prins and P. Kartaschoff (pp. 10–14).

d) **Problems of Astronomic Time**—J. P. Blaser, and W. Schuler (pp. 14–17. In French).

e) **Time Signals and Standard Frequencies**—C. Wyser (pp. 18–23. In French).

f) **The Time Service of the Swiss Post, Telegraph and Telephone Administration**—K. J. Bohren (pp. 23–32).

529.786+621.3.018.41(083.74) 984

An Improved Caesium Resonance Frequency and Time Standard—L. Essen and J. V. L. Parry. (*Nature*, vol. 184, suppl. no. 23, p. 1791; December 5, 1959.) Preliminary measurements show that a precision of a few parts in 10 inches is practicable. See 204 of 1958.

621.317.331.029.6 985

Measurement of Microwave Resistivity by Eddy-Current Loss in Spheres—T. Kohane and M. H. Sirvetz. (*Rev. Sci. Instr.*, vol. 30, pp. 1059–1060; November, 1959.) Applies to materials in which "skin effect" is appreciable in samples of ordinary size.

621.317.36:621.374.32 986

Digital Rate Synthesis for Frequency Measurement and Control—T. J. Rey. (Proc. IRE, vol. 47, pp. 2106–2112; December, 1959.) The signal whose period is to be measured is in the form of a pulse train of constant repetition rate. This train is compared with the average repetition rate of a series of nonuniformly spaced pulses from a standard source, the differences being used for frequency indication, or in a feedback loop for control purposes.

621.317.373:621.374.4 987

A Phase Multiplier—E. Augustin. (*Hochfrequenz.*, vol. 67, pp. 84–87; November. 1958.) Frequency multiplication and mixing are used in the equipment described to obtain a ten- or hundred-fold increase of very small phase angles at 10 kc. Phase multiplication by a factor of 1000 may be achieved using a carefully designed circuit and highly stable supplies.

621.317.412 988

Application of a Weakly Inhomogeneous Magnetic Field to the Quantitative Determination of Small Ferromagnetic Admixtures in Susceptibility Measurements— D. Gerstenberg. (*Z. Metallk.*, vol. 50, pp. 472–477; August, 1959.) Ferromagnetic content of 10^{-8} gram in a specimen can be determined with the apparatus described.

621.317.412 989

Absolute Measurement of Magnetic Susceptibility by a Quasistatic Induction Method—M. C. Mesnage, P. Grivet and M. Sauzade. (*Compt. rend. Acad. Sci., Paris*, vol. 249, pp. 59–60; July 6, 1959.) Changes in induction when a hollow cylinder placed in the gap of a permanent magnet is filled with a liquid or a gas are observed by a null method. Results of observations on O_2 and NO are given.

621.317.742 990

VSWR Indicators with Automatic Read-Out—M. Kollanyi and R. M. Verran. (*Electronic Engrg.*, vol. 31, pp. 666–671; November, 1959.) A probe carriage is moved along a slotted line to produce stored values of the maximum and minimum detected signals. Different methods of obtaining a direct reading of the amplitude ratio of these signals are described with circuit details.

621.317.75:534.44 991

Method of Obtaining Amplitude and Phase Spectra of a Transient Function using Graphical Input Data—W. J. Remillard. (*J. Acoust. Soc. Amer.*, vol. 31, pp. 531–534; April, 1959.) A method of harmonic analysis is describe using commercial equipment in conjunction with switching, adding and triangular-wave shaping circuits.

621.317.77:621.373 992

A System for Providing a Precise Vector Voltage—D. J. Collins and J. E. Smith. (*Electronic Engrg.*, vol. 31, pp. 684–685; November, 1959.) Schematic details are given of a means of producing, from a reference oscillator source, signals of any desired amplitude and phase.

OTHER APPLICATIONS OF RADIO AND ELECTRONICS

551.510.62:621.372.413 993

A Microwave Refractometer—R. Schünemann and W. Steffen. (*Hochfrequenz.*, vol. 67, pp. 78–83; November, 1958.) A cavity-resonator-type refractometer operating at 9.4 kmc is described and some initial measurements near the ground are discussed.

621–52:621.318.57:621.387 994

Cold-Cathode Tube Circuits—H. Liebendörfer. (*Electronic Radio Eng.*, vol. 36, pp. 436–442; December, 1959.) Describes briefly various basic control circuits using cold-cathode triodes and their application in systems for lighting control, flame detection in oil-fired boilers, thread-break detectors, etc.

621–52:621.318.57:621.387 995

ACCESS—a Static Switching System using Cold-Cathode Tubes—R. W. Brierley. (*Electronic Engrg.*, vol. 31, pp. 646–654; November, 1959.) A description of some features of an automatic production control system developed by the Austin Motor Co.

621–57:537.228.4 996

Flame-Sprayed Ceramic Dielectric for Transducers—G. V. Planner and A. Foster. (*J. Brit. IRE*, vol. 19, pp. 699–702; November, 1959.) "A high-speed electromechanical transducer system based on the Johnson-Rahbek effect is described, in which a flame-sprayed ceramic of high permittivity replaces the conventional semiconductor."

621.363 997

Thermomagnetic Generator—J. F. Elliott. (*J. Appl. Phys.*, vol. 30, pp. 1774–1777; November, 1959.) Calculations are given for a practical thermal-energy converter using gadolinium. Energy is extracted from heat sources near 20°C; reasonable efficiency and power output are claimed. See 1309 of 1949 (Brillouin and Iskenderian).

621.383.4:535–15:621.397.331.2 998

Electronic Scanning System for Infrared Imaging—M. E. Lasser, P. H. Cholet, and R. B. Emmons. (Proc. IRE, vol. 47, pp. 2069–2075; December, 1959.) An infrared image is focused on a semiconducting window of silicon at one end of a tapered tube. This is scanned by an electron beam creating free carriers locally in the semiconductor and producing a moving opaque spot which absorbs energy as the image passes through the tube to an infrared detector. The detector output is fed to a television-type monitor for display.

621.384.622.21 999

Longitudinal Movement of Electrons and Tolerances in a Linear Accelerator—A. D. Vlasov. (*Radiotekh. Elektron.*, vol. 4, pp. 295–302; February, 1959.) Determination of the injection conditions governing the acceleration and the compactness of the energy spectrum of accelerated particles.

621.385.833 1000

The Construction of Four-Pole Magnetic Lenses without Iron—A. Septier and G. Chartier. (*Compt. rend. Acad. Sci., Paris*, vol. 249, pp. 64–66; July 6, 1959.) A theoretical investigation of the magnetic field due to four-pole linear and sheet currents has been applied to the design of a strong-focusing magnetic lens which has been constructed and found to give satisfactory results.

621.387.4:621.374.3 1001

Fast Neutron Time-of-Flight Spectrometer—G. C. Neilson, W. K. Dawson, and F. A. Johnson. (*Rev. Sci. Instr.*, vol. 30, pp. 963–975; November, 1959.) A detailed description is given of a neutron spectrometer incorporating a simple time/pulse-height converter suitable for use in the mμs region. Either RF beam deflection or the gamma coincidence method is used to provide zero time indication.

621.56:537.322.1 1002

Thermoelectric Cooling—(*Electronic Engrg.*, vol. 31, pp. 690–692; November, 1959.) Refrigeration figures-of-merit of thermocouple elements are shown to be greater for certain semiconductors than for metals. Practical applications of thermoelectric cooling are discussed.

PROPAGATION OF WAVES

621.391.812.62 1003

Correlation of Meteorological Phenomena with Propagation beyond the Horizon over the Mediterranean—L. Bonavoglia. (*Alta Frequenza*, vol. 27, pp. 815–824; December, 1958.) Results of propagation tests between Sardinia and Minorca (see also 2229 of 1958) and of meteorological measurements are compared.

621.391.812.62 1004

Path Antenna Gain in an Exponential Atmosphere—W. J. Hartman and R. E. Wilkerson. (*J. Res. Nat. Bur. Stand.*, vol. 63D, pp. 273–286; November/December, 1959.) This extension of previous estimates of the loss in gain caused by tropospheric or stratospheric scattering includes the effect of an exponential model atmosphere and a scattering cross section inversely proportional to the fifth power of the scattering angle. Assuming isotropic turbulence the loss is about 2-db less than Staras' estimate (235 of 1959), which ignored the exponential atmosphere. The loss would be further reduced if anisotropic turbulence were included.

621.391.812.621 1005

Effect of Atmospheric Horizontal Inhomogeneity upon Ray Tracing—B. R. Bean and B. A. Cahoon. (*J. Res. Nat. Bur. Stand.*, vol. 63D, pp. 287–292; November/December, 1959.) The effect is negligible above 1 km. Below this, rays at elevation angles less than about 2° are sensitive to extreme horizontal inhomogeneities, as in ducting conditions. The method is partly graphical and unjustifiable for routine correction of ray paths.

621.391.812.621 1006

Partial Reflections in the Atmosphere and Long-Distance Propagation: Parts 1 and 2—F. du Castel, P. Misme, and J. Voge. (*Ann. Télécommun.*, vol. 13, pp. 209–214 and pp. 265–270; July/August and September/October, 1958.) Refractive-index measurements show the existence in the atmosphere of small layers (feuillets) each with a refractive index different from that of the mean surrounding value. Interpretation of the results suggests that the atmosphere may be considered as a dielectric medium composed of such layers which may be stable or unstable and identifiable by the slope of the index gradient through the layer.

621.391.812.63 1007

A Discussion of Ionospheric Demodulation Near Gyro-Frequency—G. L. Goodwin. (*Aust. J. Phys.*, vol. 12, pp. 157–163; June, 1959.) The effect occurs at a height of about 90 km and does not appear to decrease at dawn. A wave reflected from the F-layer is demodulated by unequal amounts during its two passages through the region. The results cannot be explained by the theory of wave interaction.

621.391.812.8 1008

Comparison of the Long-Term Prediction Methods of C.R.P.L. and S.P.I.M.—P. Halley, D. Lepechinsky and P. Mouchez. (*Ann. Télécommun.*, vol. 13, pp. 254–264; September/October, 1958.)

RECEPTION

621.391.812.3:621.317.6.087.4 1009

Correlation between Fading Signals—J. Bell. (*Electronic Tech.*, vol. 37, pp. 36–40; January, 1960.) An instrument is described for the determination of the correlation coefficient between two positive rectified fading signals using a sum-and-difference method.

621.391.821:621.3.087.4 1010

Recording of the Mean Square Value of Atmosphereic Noise—F. Carbenay. (*Compt. rend. Acad. Sci., Paris*, vol. 249, pp. 67–68; July 6, 1959.) The method used at the CNET is described. A vertical omnidirectional antenna above a metal earth is used and the square of the intensity of the linearly amplified current at a given frequency is measured by three thermocouples of different sensitivity each associated with a galvanometer. Recordings may be made photographically.

STATIONS AND COMMUNICATION SYSTEMS

621.391 1011

Poisson, Shannon, and the Radio Amateur—J. P. Costas. (Proc. IRE, vol. 47, pp. 2058–2068; December, 1959.) From a statistical analysis of the problem of communicating in a congested band of frequencies, it is concluded that reducing the required bandwidth for a service, in the hope of acquiring an exclusive channel does not always offer the best prospect of intelligible reception. The use of wider bandwidths is advocated, particularly for amateur work where specific frequencies are not allocated for individual transmitters, and for military situations in which considerable interference, unintentional or deliberate, may be expected.

621.391 1012

Error-Correcting Codes—a Linear Programming Approach—E. J. McCluskey, Jr. (*Bell Syst. Tech. J.*, vol. 38, pp. 1485–1512; November, 1959.) Theorems are given for the matrices used to construct systematic error-correcting codes and are proved for minimum-redundancy codes.

621.391:534.75 1013

Indices of Signal Detectability Obtained with Various Psychophysical Procedures—J. A. Swets. (*J. Acoust. Soc. Amer.*, vol. 31, pp. 511–513; April, 1959.) See also 3854 of 1959 (Tanner and Birdsall).

621.391:534.78 1014

Communication Efficiency of Vocoders—A. R. Billings. (*Electronic Radio Eng.*, vol. 36, pp. 449–453; December, 1959.) A vocoder, in which speech is modulated and a single sideband passed to the analyzer filters through an amplitude limiter, is shown on comparison with the convention vocoder to have a greater communication efficiency, this being defined as the ratio of the actual rate of information to the rate of transmission in an ideal system subject to the same restrictions.

621.391:621.376.5 1015

Ideal Binary Pulse Transmission by A.M and F.M.—E. D. Sunde. (*Bell Syst. Tech. J.*, vol. 38, pp. 1357–1426; November, 1959.) Intersymbol interference can be avoided in binary pulse transmission by FM without the need for a wider channel bandwidth than in DSB AM for equal pulse transmission rates. Explici general expressions are derived for the appropriate shaping of the band-pass channel. Th optimum division of channel shaping between transmitting and receiving filters for FM and AM with random noise, and the relation between error probability and signal/noise rati are discussed.

621.391.822 1016

Transition Probability Densities of the Smoothed Random Telegraph Signal—W. M. Wonham. (*J. Electronics Control*, vol. 6, pp. 376–384; April, 1959.) An extension of earlier analysis (3634 of 1958) to derive the transition probability functions of the associated Markov process.

621.395:621.372 1017

The South Lancashire Radiophone Service—(*Brit. Commun. Electronics*, vol. 6, pp. 858–861; December, 1959.)

Part 1—The General System—L. T. Arman (pp. 858–860). A VHF mobile radio service provides communication between land mobile stations and the public telephone network.

Part 2—The Radio-Telephone Equipment—B. Armstrong (pp. 860–861). A discussion of the technical specification.

621.395:621.376.56 1018

A Delta Modulation System using Junction Transistors—B. E. Williams. (*Electronic Engrg.* vol. 31, pp. 674–680; November, 1959.) A speech link operating at a digit frequency of 14 kc uses alternating binary encoding—a form in which the signal has no dc component—and requires less bandwidth than normal binary code.

621.395.665.1:534.861 1019

Contribution on the Reciprocal Control of Dynamic Range—H. Völz. (*Hochfrequenz.*, vol. 67, pp. 87–94; November, 1958.) Six-terminal networks are introduced in this theoretical consideration of dynamic compression and restitution of the original dynamics after the signal has passed through a noisy communication channel. Practical systems designed to avoid the occurrence of transients are discussed.

621.396.65 1020

Convention on Radio Links—(*Alta Frequenza*, vol. 27, pp. 578–832; December, 1958.) Third issue covering the proceedings of a convention held in Rome, June 5–8, 1957. Second issue: 2014 of 1959. Abstracts of some of the papers are given individually; titles of others are as follows:

a) **Microwave Amplification by Earthed-Grid Triodes**—G. B. Stracca (pp. 578–614).

b) **Applications of Ferrites in Microwave Radio Links**—M. Vadnjal (pp. 615–628).

c) **Frequency Control of Klystrons by Reference Cavity**—L. Del Bello (pp. 629–633).

d) **On the Improvement of Linearity of Reflex Klystrons used as Frequency-Modulated Oscillators**—G. Cicconi (pp. 634–682.)

e) **New Components for Miniaturized Microwave Radio Links**—M. Mueller (Müller) (pp. 683–698. In English).

f) **Problems of Automatic Switching**—A. Ricagni (pp. 699–715).

g) **Criteria and Measurements of Suitability of Equipment for Radio Links**—G. Monti-Guarnieri (pp. 716–751).

h) **A 6000-Mc/s Communication System for 300 Telephone Channels**—E. Viti (pp. 752–778).

i) **Multiplex for Three High-Quality Music Channels**—A. Pasini (pp. 779–789).

j) **Directive Aerials with Dual Polarization**—G. Parmeggiani (pp. 794–814).

621.396.74.029.51/.53(43) 1021

Long and Medium-Wave Transmitters in the German Federal Republic—(*Rundfunktech. Mitt.*, vol. 2, pp. 304–307; December, 1958.) *See* also 1023 below.

621.396.74.029.55(43) 1022

Short-Wave Frequencies in the German Federal Republic—(*Rundfunktech. Mitt.*, vol. 2, p. 303; December, 1958.)

621.396.74.029.62(43) 1023

List of VHF Transmitters in the German Federal Republic—(*Rundfunktech. Mitt.*, vol. 2, pp. 300–303; December, 1958.) The lists and map of transmitter locations give the position as of November 1, 1958.

621.396.931 1024

Radio Telephony in French Express Trains—[*Engineer* (*London*), vol. 208, pp. 158–159; August 28, 1959.)] On the route Paris-Lille a VHF link operating at 160 mc is provided between trains and a chain of 11 lineside stations with a cable connection to a Paris exchange.

SUBSIDIARY APPARATUS

621.3.087.4:621.396.96 1025

Electronic Line-Storage Device for the Compression of the Frequency Band of Periodically Recurring Signals, particularly of Radar Displays—K. Lange. (*Nachrichtentech. Z.*, vol. 11, pp. 619–627; December, 1958.) The operation of a CR -tube line-storage system is discussed. Equipment is described for measuring the integrating characteristics of such storage devices. See also 3744 of 1956 (Meinke and Groll).

621.316.722.027.5:621.385.4 1026

A Small, High-Voltage, Regulated Power Supply with Variable Output—J. D. O'Toole. (*Electronic Engr.*, vol. 31, pp. 681–683; November, 1959.) The design of a regulating circuit operating in the range 1–4kv is described which uses a beam tetrode as a series regulator and two double triodes in the feedback circuit.

621.316.722.073.3:621.385.032.213 1027

A Transistorized L. T. Regulator—J. H. Deichen. (*Electronic Engr.*, vol. 31, pp. 688–689; November, 1959.) "The methods of providing a stabilized dc supply for tube heaters are examined and their limitations are discussed. A simple circuit using a transistor and two Zener diodes is then given and its design and performance described."

TELEVISION AND PHOTOTELEGRAPHY

621.397:621.391.8.029.63 1028

Some Aspects of Television Reception on Band V—H. N. Gant. (*J. Brit. IRE*, vol. 19, pp. 727–733; November, 1959.) Band-V television receiver design problems are considered with regard to available components. Suitable antenna systems and their performance figures are noted.

621.397.132.001.4:621.317.755 1029

A Vectorscope Unit—K. G. Freeman. (*Electronic Engrg.*, vol. 31, pp. 655–658; November, 1959.) Circuit details are given of an instrument which uses the principles of coherent detection to provide a vectorial display of NTSC subcarrier chrominance signals.

621.397.232.2:621.391.82 1030

Co-channel Television Interference and its Reduction—E. W. Chapin, L. C. Middlekamp, and W. K. Roberts. (IRE TRANS. ON BROADCAST TRANSMISSION SYSTEMS, vol. PGBTS-10, pp. 3–24; June, 1958. Abstract, PROC. IRE, vol. 46, p. 1665; September, 1958.)

621.397.232.2 :621.391.82 1031

Reduction of Co-channel Television Interference by Very Precise Offset Carrier Frequency—L. C. Middlekamp. (IRE TRANS. ON BROADCAST TRANSMISSION SYSTEMS, vol. PGBTS-12, pp. 5–10; December, 1958.) The effect on picture degradation of frequency-offset variation is investigated, and the improvement in picture quality to be gained by using precise offset values held to a close tolerance is discussed.

621.397.232.2:621.391.82 1032

Investigation of the Operation of Television Transmitters with Precise Offset-Carrier Frequencies—H. Hopf. (*Rundfunktech. Mitt.*, vol. 2, pp. 265–276; December, 1958.) The reduction of the transmitter-frequency tolerance to about ±2.5 cps results in an improvement by more than 10 db in the RF protection ratio (*see* also 1030 above). Curves of protection ratios are plotted for various types of carrier-offset and include a set of curves of recommended ratios for the 625-line CCIR system, with a reference-interference ratio of 30 db for carrier offset equal to $\frac{2}{3}\times$ line frequency.

621.397.334 1033

A New Approach to Kinescope Beam Convergence—J. W. Schwartz and P. E. Kaus. (IRE TRANS. ON ELECTRON. DEVICES, vol. ED-5, pp. 275–282; October, 1958. Abstract, PROC. IRE, vol. 47, p. 495; March, 1959.)

621.397.334:621.374.33 1034

A Gating Circuit for Single-Gun Colour Television Tubes.—K. G. Freeman. (*J. Brit. IRE*, vol. 19, pp. 667–677; November, 1959.) Gating circuits and their limitations are discussed. A new gating circuit is described, which employs low-leve gating of the red, green and blue video signals in conjunction with a wide-band amplifier.

621.397.6.001.4 1035

Laboratory Television Transmitter for the Intermediate-Frequency Range—P. Klopf. (*Rundfunktech. Mitt.*, vol. 2, pp. 253–264; December, 1958.) A modulator unit is described for use in tests on residual-sideband transmission for the 625-line CCIR system. The quality of transmission via the modulator and a standard IF receiver is examined.

621.397.61:535.88 1036

Further Development of the Television Episcope—R. Theile and F. Pilz. (*Rundfunktech. Mitt.*, vol. 2, pp. 290–292; December, 1958.) Details are given of an improved version of the equipment described in 1374 of 1959.

621.397.7—182.3 1037

A Contribution to the Design and Construction of Television Outside-Broadcast and Film-Recording Vehicles—G. Schadwinkel and H. Käding. (*Rundfunktech. Mitt.*, vol. 2, pp. 277–289; December, 1958.) Vehicles developed by the West German radio organizations and their equipment are described.

621.397.72 1038

Some Aspects of the Design of a Small Television Station—A. Harris. (*J. Brit. IRE*, vol. 19, pp. 705–721; November, 1959.) "Some of the factors governing the choice of equipment for use in small commercial television stations in isolated areas are discussed. Specific reference is made to two different types of installation at station ZBM-TV, Bermuda, using the same basic equipment."

621.397.74(43) 1039

The Television Network of the German Federal Republic—(*Rundfunktech. Mitt.*, vol. 2, pp. 293–299; December, 1958.) Tabulated data on television transmitters as of November 1, 1958, with maps showing their location and that of television links.

621.397.743 1040

Climatic Resistance, Operational Reliability, and Emergency Circuitry of Television Frequency Translators—K. Fischer, H. J. Fraisse, and W. Marks. (*Telefunken Ztg.* vol. 32, pp. 47–58, March, 1959. English summary, pp. 73–74.) The effects of outdoor operation on unattended television relay equipment are discussed. Means of minimizing these effects and of ensuring the maintenance of services are illustrated by examples of specially designed units.

TRANSMISSION

621.396.61:621.372.51 1041
Gauging Transmitters to Overcome Jamming—P. W. Esten. (*Electronics*, vol. 32, pp. 68–70; November 27, 1959.) A combining network enables four transmitters to feed a common antenna to increase radiated power.

621.396.61:621.391.82 1042
Interference Area of a Transmitter for Tropospheric-Scatter Radio Links—A. Chinni (*Alta Frequenza*, vol. 27, pp. 825–832; December, 1958.) A nomogram has been constructed for obtaining the distance from a transmitter at which the interference field intensity exceeds a certain level for 0.1 per cent of the time, for any given frequency, radiated power, antenna gain and radiation pattern.

TUBES AND THERMIONICS

621.382.2 1043
Zener Diodes—their Properties and Applications—J. M. Waddell and D. R. Coleman. (*Wireless World*, vol. 66, pp. 17–21; January, 1960.)

621.382.2:621.391.822 1044
The Noise of Diodes—W. Drechsel. (*NachrTech.*, vol. 8, pp. 538–541; December, 1958.) Fundamental causes of LF and HF noise in semiconductor diodes are considered and the choice of diode characteristics for optimum performance in static, dynamic, and mixer operation is discussed.

621.382.2/.3:539.12.04 1045
How Radiation Affects Semiconductor Devices—M. F. Wolff. (*Electronics*, vol. 32, pp. 55–57; November 27, 1959.) Transistor and diode damage and the change in circuit characteristics due to radiation effects are noted. Radiation-resistant devices such as the thin-base Ge transistor and the tunnel diode are mentioned.

621.382.23 1046
The Tunnel Diode—Circuits and Applications—I. A. Lesk, N. Holonyak, Jr. and U. S. Davidsohn. (*Electronics*, vol. 32, pp. 60–64; November 27, 1959.) Details are given of the characteristics of tunnel diodes possessing a high negative conductance and a high resistance to nuclear-radiation and temperature effects. Their applications in amplifier, oscillator and detector circuits are illustrated.

621.382.23:621.372.44 1047
Surface-Dependent Losses in Variable-Reactance Diodes—D. E. Sawyer. (*J. Appl. Phys.*, vol. 30, pp. 1689–1691; November, 1959.) High-frequency performance is lowered by these losses which cause the series equivalent resistance to be larger than the integrated bulk resistance. The effect is shown to vary with surrounding atmosphere and an explanatory model is given.

621.382.3:621.391.822 1048
The Noise Equivalent Circuit of the Transistor—G. Winkler. (*NachrTech.*, vol. 8, pp. 542–548; December, 1958.) The representation of transistor noise in the form of an equivalent noise three-pole network using noise parameter measurements or by an equivalent circuit based on calculation is described.

621.382.3.012.6 1049
Transistor Matching Impedances—A. G. Bogle. (*Electronic Tech.*, vol. 37, pp. 28–30; January, 1960.) Calculations are described relating the variation of input impedance, output impedance and gain of a Type-OC 71 transistor to changes of operating point and negative feedback.

621.382.3.032.27 1050
Application of a Photogravure Process to the Deposition of Metal Contacts on Semiconductors—P. Michelet and J. Vareine. (*Onde élect.*, vol. 39, pp. 858–862; November, 1959.) A photosensitive synthetic resin is used in the process which is applied to HF Si transistors. Reference is made to the elimination of the superficial oxide layer by the process.

621.382.333 1051
An 85-Watt-Dissipation Silicon Power Transistor—R. W. Aldrich, R. H. Lanzl, D. E. Maxwell, J. O. Percival, and M. Waldner. (IRE Trans. on Electron Devices, vol. ED-5, pp. 211–215; October, 1958. Abstract, Proc. IRE, vol. 47, p. 494; March, 1959.)

621.382.333 1052
Large-Signal Rise Times in Junction Transistors—W. W. Gärtner. (IRE Trans. on Electron Devices, vol. ED-5, p. 316; October, 1958.) An investigation of collector current response using a more exact expression for α_N than that used by Moll (885 of 1955) yields considerably higher values for the large-signal rise times.

621.382.333 1053
The Physical Interpretation of Measurements on Transistors—F. J. Hyde (*J. Electronics Control*, vol. 6, pp. 362–364; April, 1959.) The equation for the effective lifetime of holes in the base given by Deb and Daw (2043 of 1959) is shown to be not generally valid, and a modified equation is derived.

621.382.333:621.317.3 1054
Measurement of the High-Frequency Base Resistance and Collector Capacitance of Drift Transistors—F. J. Hyde and T. E. Price. (*J. Electronics Control*, vol. 6, pp. 347–355; April, 1959.) A modified Turner circuit (354 of 1955) is used to determine $r_{bb'}$ and c_c separately. The effect of stray emitter-collector capacitance on the measurements is analyzed.

621.382.333:621.318.57 1055
Two-Terminal Asymmetrical and Symmetrical Silicon Negative-Resistance Switches—R. W. Aldrich and N. Holonyak, Jr. (*J. Appl. Phys.*, vol. 30, pp. 1819–1824; November, 1959.) "By making use of an emitter region shorted by a metallic contact to an adjacent base region, a new form of *p-n-p-n* switch is obtained. Several new structures are described, including a symmetrical (or ac) switch. Typical experimental results on switches which break down in the range from 25 to 40 volts are presented."

621.382.333.33 1056
A Silicon *p-n-p-n* Power Triode—K. Kawana and T. Misawa. (*J. Electronics Control*, vol. 6, pp. 324–332; April, 1959.) A simplified theory assuming equal ionization for electrons and holes is presented which explains the controlling effect of base current on the *I/V* characteristics of the triode. Characteristics of a developmental triode are given.

621.382.333.4 1057
The Emitter Tetrode—R. A. Gudmundsen. (IRE Trans. on Electron Devices, vol. ED-5, pp. 223–225; October, 1958. Abstract, Proc. IRE, vol. 47, p. 495; March, 1959.)

621.383.4 1058
The Limiting Sensitivity and the Noise Spectrum of Germanium Junction Photodiodes—L. Ya. Pervova. (*Radiotekh. Elektron.*, vol. 4, pp. 330–334; February, 1959.) The sensitivity threshold was of the order of 10^{-10} lumen second $^{1/2}$ with a light-beam modulation frequency 70 cps. The noise spectrum in the range 0.5 cps to several hundres of cps obeys the $1/f$ law; for higher frequencies the noise is close to the shot noise of the photodiode dark current.

621.385 (083.72) 1059
Vacuum Diodes and Grid-Controlled Vacuum Tubes: Terminology—(*Nachrichtentech. Z.*, vol. 11, pp. 635–644; December, 1958.) A list of 138 terms and their definitions recommended by the Nachrichtentechnische Gesselschaft; the corresponding English and French terms are given in most cases. This is an amended version of 652 of 1958.

621.385.1:621.391.822 1060
Flicker Noise of Valves in the L.F. Region—H. Mutschke. (*NachrTech.*, vol. 8, pp. 585–590; December, 1958.) The mechanism of flicker noise is discussed with reference to previous work [*e.g.*, 1284 of 1957 (Lindemann and van der Ziel)] and results are given of tests on various types of tubes to determine the dependence of flicker noise on heater voltage, anode current and running time.

621.385.3.029.63 1061
PC86, a Newly Developed Grounded-Grid Triode for Decimetre Waves (U.H.F.)—H. Bünger. (*Telefunken Ztg.*, vol. 31, pp.262–265; December, 1958. English summary, p. 274.) The glass tube described is designed for operation at frequencies up to 800 mc; its amplification factor is 68, and its slope 14 ma/volt.

621.385.6 1062
Periodic Electrostatic Focusing of a Hollow Electron Beam—C. C. Johnson. (IRE Trans. on Electron Devices, vol. ED-5, pp. 233–243; Abstract, Proc. IRE, vol. 47, p. 495; March, 1959.)

621.385.6 1063
A Symmetry Property of Space-Charge Waves in Accelerated Electron Beams—I. P. Shkarofsky. (IRE Trans. on Electron Devices, vol. ED-5, pp. 283–288; October, 1958. Abstract, Proc. IRE, vol. 47, p. 495; March, 1959.)

621.385.6 1064
On Speed Charge Waves—R. H. C. Newton. (*J. Electronics Control*, vol. 6, pp. 321–323; April, 1959.) Comment on 2058 of 1959 (Trevena).

621.385.6 1065
Calculation of Electron-Beam Divergence at Medium Gas Pressures—B. H. Wadia. (*J. Electronics Control*, vol. 6, pp. 307–320; April, 1959.) A method is described involving step-by-step integration, by which the beam profiles in the presence of gas at $10^{-5}-10^{-7}$ mm Hg can be estimated. Universal curves are given which enable the designer to estimate the modification of the "perfect-vacuum" behavior ($<10^{-8}$ mm Hg) to be expected in practical tubes.

621.385.6:621.375.9 1066
The Kinetic Power Theorem for Parametric, Longitudinal, Electron-Beam Amplifiers—H. A. Haus. (IRE Trans on Electron Devices, vol. ED-5, pp. 225–232; October, 1958. Abstract, Proc. IRE, vol. 47, p. 495; March, 1949.)

621.385.6:621.391.822 1067
New Method of Measuring the Noise Parameters of an Electron Beam—S. Saito. (IRE Trans. on Electron Devices, vol. ED-5, pp. 264–275; October, 1958. Abstract. Proc. IRE, vol. 47, p. 495; March, 1959.)

621.385.62 1068
A Multicavity Klystron with Double-Tuned

Output Circuit—H. J. Curnow and L. E. S. Mathias. (*Proc. IEE*, pt. B, vol. 106, pp. 487–488; September, 1959. Discussion, pp. 492–494.) An improved bandwidth (5.3 per cent–6.3 per cent for 2.5-mw output) has been obtained from a 6-cavity pulsed S-band klystron amplifier by the use of a double-tuned output circuit.

621.385.62:621.376.32 1069

A Simple Investigation of the Cross-Modulation Distortion arising from the Pulling Effect in a Freqency-Modulated Klystron—D. T. Gjessing. (*Proc. IEE*, pt. B, vol. 106, pp. 473–477; September, 1959. Discussion, pp. 492–494.) An expression for the distortion spectrum is derived theoretically, and families of curves showing severity of distortion are plotted. It is shown that small mis-matches of the output feeder give serious crosstalk.

621.385.624 1070

Large-Signal Analysis of the Multicavity Klystron—S. E. Webber. (IRE TRANS ON ELECTRON DEVICES, vol. ED-5, pp. 306–315; October, 1958. Abstract, PROC. IRE, vol. 47, p. 496; March, 1959.)

621.385.63 1071

Space and Time Harmonics in Electron Streams—R. Müller, (*Arch. elekt. Übertragung*, vol. 12, pp. 527–532; December, 1958.) Wave propagation is analyzed in systems with space-periodic structure which changes with time. These conditions arise when a high-intensity traveling wave interacts with an electron beam; harmonic frequencies are then generated. See also 2962 of 1957.

621.385.63 1072

General Design Procedure for High-Efficiency Travelling-Wave Amplifiers—J. E. Rowe and H. Sobol. (IRE TRANS. ON ELECTRON DEVICES, vol. ED-5, pp. 288–300; October, 1958. Abstract, PROC. IRE, vol. 47, p. 495; March, 1959.)

621.385.63 1073

Design and Performance of Coupled-Helix Transducers for Travelling-Wave Tubes—T. S. Chen. (*J. Electronics Control*, vol. 6, pp. 289–306; April, 1959). Discussion of systems in which coupling between a traveling-wave-tube helix and the input or output coaxial cable is achieved by connecting the inner of the cable to a short helix wound round the outside of the main helix. The choice of pitch for the coupling helix is discussed and experimental results are given.

621.385.63 1074

Approximate Analytic Expressions for TWT Propagation Constants—W. H. Louisell. (IRE TRANS ON ELECTRON DEVICES, vol. ED-5, pp. 257–259; October, 1958. Abstract. PROC. IRE, vol. 4, p. 495; March, 1959.)

621.385.63 1075

Travelling-Wave-Tube Propagation Constants for Finite Values of Gain per Wavelength—D. A. Dunn, G. S. Kino, and G. W. C. Mathers. (IRE TRANS. ON ELECTRON DEVICES, vol. ED-5, pp. 243–251; October, 1958. Abstract, PROC. IRE, vol. 47, p. 495; March, 1959.)

621.385.63 1076

Improvement of Travelling-Wave-Tube Efficiency through Collector Potential Depression—F. Sterzer. (IRE TRANS. ON ELECTRON DEVICES, vol. ED-5, pp. 300–305; October, 1958. Abstract. PROC. IRE, vol. 47, pp. 495–496; March, 1959.)

621.385.63 1077

Theory and Behaviour of Helix Structures for a High-Power Pulsed Travelling-Wave Tube—G. W. Buckely and J. Gunson. (*Proc. IEE*, pt. B, vol. 106, pp. 478–486; September, 1959. Discussion, pp. 492–494.) A multistart helix structure which may be water-cooled is considered theoretically and experimentally. There is reasonable agreement between measurements on 4- and 8-start structures and calculations of impedance and phase velocity on equivalent bounded sheath helices.

621.385.63 1078

Traveling-Wave-Tube Analogue—G. D. Sims and I. M. Stephenson. (*Electronic Tech.*, vol. 37, pp. 20–24, January, 1960.) The properties of any traveling-wave tube whose structure possesses equivalent parameters can be simulated, regardless of its actual physical form, by using the lumped-circuit principle and designing the inductance drift-tube structure to provide a given impedance and phase shift. The model described was designed primarily to investigate forward-wave interaction.

621.385.633 1079

Velocity and Current Distributions in the Spent Beam of the Backward-Wave Oscillator—J. W. Gewartowski. (IRE TRANS. ON ELECTRON DEVICES, vol. ED-5, pp. 215–222; October, 1958. Abstract, PROC. IRE, vol. 47, pp. 494–495; March, 1959.)

621.385.633.1 1080

Influence of Magnetic Focusing Fields and Transverse Electron Motion on Starting Conditions for Spurious Oscillations in O-Type Backward-Wave Oscillators—H. G. Kosmahl. (IRE TRANS. ON ELECTRON DEVICES, vol. ED-5, pp. 252–257; October, 1958, Abstract, PROC. IRE, vol. 47, p. 495; March, 1959.

621.385.69:621.372.2 1081

A New Wide-Band Thermionic Valve—T. Kojima. (*Onde élect.*, vol. 39, pp. 876–833; November, 1959.) Theoretical and practical considerations in the design of a distributed-amplifier-type tube are discussed [see 902 of 1954 (Lewis)]. Results obtained with a prototype tube operating from low frequencies up to 70 mc are compared with theoretical calculations.

621.387:621.362 1082

"Open-Circuit" Voltages in the Plasma Thermocouple—H. W. Lewis and J. R. Reitz. (*J. Appl. Phys.*, vol. 30, pp. 1838–1839; November, 1959.) Further discussion of the plasma diode (366 of January) clarifying the mechanism involved.

MISCELLANEOUS

621.38/.39:061.3 1083

Annual Convention of the Popov Society in Moscow, 12th–17th May, 1958—F. H. Lange. (*NachrTech.*, vol. 8, pp. 591–592; December, 1958.) A brief report on some of the papers presented at the convention, and a complete list of titles and authors covering the following four of twelve sections: a) information theory, b) antenna installations, c) semiconductor and miniature circuit elements, and d) electronics.

Translations of Russian Technical Literature

Listed below is information on Russian technical literature in electronics and allied fields which is available in the U. S. in the English language. Further inquiries should be directed to the sources listed. In addition, general information on translation programs in the U. S. may be obtained from the Office of Science Information Service, National Science Foundation, Washington 25, D. C., and from the Office of Technical Services, U. S. Department of Commerce, Washington 25, D. C.

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The Institute of Radio Engineers, Inc.
1 East 79 Street, New York 21, N.Y.

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AP:	Antennas and Propagation
AU:	Audio
AC:	Automatic Control
BTR:	Broadcast and Television Receivers
BC:	Broadcasting (Formerly Broadcast Transmission Systems)
CT:	Circuit Theory
CS:	Communications Systems
CP:	Component Parts
E:	Education
ED:	Electron Devices
EC:	Electronic Computers
EM:	Engineering Management
EWS:	Engineering Writing and Speech
IE:	Industrial Electronics
IT:	Information Theory
I:	Instrumentation
ME:	Medical Electronics
MTT:	Microwave Theory and Techniques
MIL:	Military Electronics
NS:	Nuclear Science
PT:	Production Techniques
RFI:	Radio Frequency Interference
RQC:	Reliability and Quality Control
SET:	Space Electronics and Telemetry (Formerly Telemetry and Remote Control)
UE:	Ultrasonics Engineering
VC:	Vehicular Communications

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Carpenter, W. E.: AC Dec 185
Carr, J. W.: I Sep 39
Carroll, J. M.: EWS Dec 78
Cason, F. L.: E Mar 10
Cassidy, J. D.: E Jun 73
Castriota, L.: CT Mar 102, Sep 317
Cazanjian, R.: RQC Jun 70
Cederbaum, I.: CT May 127; IT May 127; SET Sep 111
Cell, J. W.: I Dec 112
Chait, H. N.: MTT Jan 38
Chandler, T. A.: CS Jun 115
Chaney, W. G.: VC Apr 67
Chang, C. M.: ED Apr 154
Chang, H.: EC Dec 458
Chang, N. C.: ED Oct 437
Chang, S. S. L.: AC Dec 172
Chang, W. S. C.: AP Jul 207, Oct 359
Chao, S. C.: EC Mar 8
Chao, S. K.: EC Sep 317
Chapline, J. D.: EWS Jun 42
Chaskin, W. S.: CS Jun 92
Chenoweth, R. D.: E Sep 134
Chernin, M. G.: AP Jul 213
Chestnut, H.: AC Dec 21
Chien, R. T.: EC Sep 400, IT Jun 91
Chisholm, J. H.: CS Sep 195
Chisholm, R. N.: AP Dec S279
Chodorow, M.: ED Jan 48, Jul 352
Chow, C. K.: EC Jun 230
Chow, Y.: CT Jun 233
Chu, T. S.: AP Oct 436, Dec S273
Clark, F. J.: MIL Oct 175
Clark, L. C., Jr.: ME Mar 18
Clark, R. E.: EWS Jan 12
Clauss, R. H.: ME Dec 246
Clemmow, P. C.: AP Dec 57
Cline, J. F.: MTT Jan 121, Jul 369
Clymer, A. B.: EC Sep 381
Clynes, M.: AC Dec 45
Coates, C. L.: CT Jun 170
Cocke, J.: IT Mar 33
Cogan, S.: SET Sep 117
Cohen, M.: MTT Oct 430
Cohn, M.: MTT Apr 202, Oct 478
Cohn, S. B.: MTT Jan 149, Apr 190, Oct 453
Cole, R. I.: EM Mar 12
Coleman, P. D.: MTT Jan 42, Jul 391
Collier, R. J.: ED Jan 9
Collin, R. E.: AP Jan 62, Jul 276
Collins, H. B., Jr.: BC Nov 2
Combellick, T.: CS Jun 110
Cook, D. M.: E Mar 10
Cooper, M.: CS Jun 133
Cooper, T.: ME Dec 207
Cordell, A. R.: ME Dec 228
Corkhill, D. J.: MIL Oct 160
Corner, G. W.: ME Mar 6
Cornetet, W. H., Jr.: ED Apr 236
Coroniti, S. C.: CS Jun 121
Cotcher, A. L.: EWS Jan 34
Cote, A. J., Jr.: CT Jun 232, Sep 323
Cottony, H. V.: AP Jan 87
Cowan, W. M.: IT Sep 106
Cox, F. B.: EC Jun 186
Coxe, F. S.: SET Jun 87
Cozens, J. H.: CP Jun 114
Cranna, N. G.: ED Oct 384
Crawford, H. D.: ME Sep 141
Crawford, R. V.: VC Apr 20
Cross, A. H.: EWS Jun 49
Crowley, J. C.: SET Mar 47
Cruz, J. B., Jr.: CT Mar 133, Dec 393
Cruzan, O. R.: AP Oct 345
Culbertson, A. F.: VC Sep 73
Cullen, A. L.: AP Dec S219
Culshaw, W.: MTT Apr 221
Cumming, W. A.: AP Jul 226
Cummings, D. B.: NS Sep 23
Curtis, G. L.: CS Jun 92
Curtis, H. E.: CS Sep 161
Cutler, B.: ANE Jun 135, 142
Cutrell, E. A.: ANE Jun 67
Cutrona, L. J.: AC Nov 137

D

Daggett, D. H.: EC Sep 335
Danko, S. F.: PT Aug 29
Dannenberg, K. K.: AC Dec 30
Darlington, S.: CT May 1; IT May 1
Davidson, D. S.: NS Jun 53
Davis, D. E.: PT Jun 29
Davis, L. I.: MIL Jan 4
Deal, W. R.: CS Jun 71
Debart, H. P.: CT May 14; IT May 14
De Beurs, P.: ED Apr 169
DeBolt, H. E.: NS Jun 74
de Carvalho Fernandes, A. A.: AP Jan 39
Decker, R. P.: AP Apr 188
den Broeder, G. G., Jr.: RQC Jun 34
Denison, A. B., Jr.: ME Dec 220, 277
Dennis, F. L.: CT Sep 323
Depian, L.: ED Apr 125
Deschamps, G. A.: AP Dec S371
Desmares, P.: BTR Dec 64
Desoer, C. A.: CT Sep 244, Dec 397
Deutsch, S.: CT Jun 214
Diamantides, N. D.: ANE Mar 16
Djorup, R. S.: SET Sep 148
Doherty, L. H.: AP Apr 117, Oct 419
Dolphin, L.: AP Apr 127
Dombrowski, G. E.: ED Oct 419
Dome, R. B.: AU Jan–Feb 16, Mar–Apr 29
Domeshek, S.: MIL Jul 87
Donald, D. G.: CS Jun 115
Dow, D. G.: ED Jan 106
Drubin, M.: CT Sep 325, Dec 386
Dubbe, R. F.: AU May–Jun 76
Duncan, J. W.: MTT Apr 257
Dunn, D. A.: ED Jul 294
Dunn, F. L.: SET Jun 82
Dunn, H. K.: AU May–Jun 47
Durkee, A. L.: CS Dec 272
Dwonczyk, M.: ANE Dec 228
Dyson, J. D.: AP Jan 102, Apr 181, Oct 329
Dzik, A.: VC Apr 58

E

Early, J. M.: ED Jul 322
Edwards, J. S.: ME Mar 39
Egan, J. F.: AC Dec 71
Ehrenpreis, D.: PT Jun 11; RQC Jun 70
Ehrenspeck, H. W.: AP Oct 379
Ehricke, K. A.: MIL Apr 58
Eisenberg, R. M.: MIL Jul 105
Elkind, J. I.: AC May 44
Ellerbruch, D. A.: CP Mar 42
Elliott, R. S.: AP Jan 87, Oct 435
Ellis, P. H.: AC Nov 43
Ellis, R. M.: ME Dec 204
Elspas, B.: CT Mar 45
Engen, G. F.: MTT Jul 351
Englund, J. W.: BTR Jan 13
Enslein, K.: I Mar 3, Sep 51; IE Jan 17; NS Mar 14
Enslow, G. M.: NS Jun 49
Erickson, K. E.: CT Mar 124
Espersen, G. A.: ED Jan 115
Evans, A. G.: AU Sep–Oct 116
Evans, D. H.: PT Jun 4
Evans, R. L.: ME Dec 266
Evans, W. R.: AC Dec 197

F

Fahey, W. J.: E Jun 75
Fannin, B. M.: AP Jul 258
Farber, R. J.: BTR May 50
Farmer, D. J.: MIL Oct 178
Farrall, W. R.: ME Dec 198
Feder, W.: ME Dec 240, 250
Feiner, A.: CS Dec 302
Feingold, W.: BTR Jan 10
Feinstein, J.: ED Jan 9
Feistman, M. L.: EWS Jan 22
Feldman, N. W.: VC Sep 27
Felsen, L. B.: AP Apr 168, Dec S231; MTT Jan 102
Ferguson, D. J.: ME Dec 291
Fettweis, A.: CT Sep 252
Fiedler, C. J.: AC Dec 81
Fielder, D. C.: CT Mar 81, Jun 158, Sep 282
Filipowsky, R.: CS Jun 95
Fink, B. R.: ME Sep 119
Fink, J. S.: ME Sep 141
Finkelstein, J.: PT Aug 50
Firle, T. E.: ED Jul 330
Fish, P. E.: BC Feb 14
Fisher, J. C.: EM Jun 46, Sep 65
Fiskin, J. M.: AP Jul 240
Fitch, M. E.: IE Jan 25
Fitzner, A. O.: IE Apr 19
Fleri, D.: MTT Jan 23
Flügge-Lotz, I.: AC Dec 109
Fogel, L. J.: ANE Dec 228
Foldes, P.: AP Jan 74
Fontaine, A. B.: CT May 60; IT May 60
Forgie, C. D.: AC May 44
Fosberg, A. M.: ME Dec 246
Foster, J. H.: RFI May 11
Fountain, A. M.: EWS Jun 46
Fournier, R. V.: BTR Dec 46
Fowler, A. D.: CS Sep 173
Fowler, E.: AU Nov–Dec 169
Fraade, D. J.: IE Dec 1
Frank, K.: ME Jun 85
Frankel, S. P.: EC Sep 271
Franklin, D. L.: ME Dec 204
Franz, K.: AP Oct 353, Dec S68
Freethey, F. E.: MTT Jul 388
Freidland, B.: CT Mar 61; IT Sep 114, 136
Friedman, B.: AP Dec S227
Freidman, M. P.: ME Sep 121
Freiman, C. V.: CT May 71; IT May 71, Jun 62
Freimer, M.: AC Nov 10; IT Mar 25
Frihart, H. N.: BTR Dec 54
Froelich, R. W.: AC Dec 139
Frost, H. B.: ED Jul 315
Frumin, M. J.: ME Mar 30
Fry, D. L.: ME Dec 252, 259, 264
Fryer, W. D.: CT Jun 144
Fujisawa, T.: CT Sep 261
Fukada, M.: CT Sep 277
Fullwood, R.: EC Dec 498
Furutsu, K.: AP Dec S209

G

Gabriel, W. F.: MTT Oct 481, 482
Galbraith, R. A.: E Apr 50
Galejs, J.: IT Jun 79, Sep 106; SET Dec 179
Gallagher, H. E.: ED Oct 390
Gamo, H.: CT May 283; IT May 283
Gardner, C. S.: AP Dec S87
Gariano, W. F.: ED Jan 90
Garner, H. L.: EC Mar 25, Jun 140
Garver, R. V.: MTT Apr 272
Gates, C. R.: AC Dec 34
Gau, L.: IE Jul 43
Geddy, G. B.: PT Aug 27
Geffe, P. R.: CT Mar 129, Dec 395
Gerardi, F. R.: CT Jun 197
Gerhold, R. A.: PT Aug 12
Germano, C. P.: AU Jul–Aug 96
Gerosa, G.: AP Dec S471
Gerst, I.: MTT Oct 475
Getting, I. A.: MIL Jan 19
Gianoplus, A. S.: SET Jun 66
Giesselman, A. C.: VC Sep 4
Giguere, W. J.: EC Dec 432
Gilbert, E. G.: EC Jun 204
Gilbert, E. O.: EC Sep 391
Gill, A.: EC Dec 486; IT Jun 52
Gillespie, E. F. F.: AP Dec S219
Ginsburg, S.: EC Mar 13, Sep 346, Dec 441
Ginzton, E. L.: ED Jan 64
Glass, H. I.: MTT Apr 295
Glenn, A. B.: CS May 14
Glomb, W. L.: CS Dec 284
Golay, M. J. E.: SET Dec 186
Gold, B.: IT Mar 17, 25
Gold, L.: SET Dec 162
Gold, R. D.: EC Sep 287
Goldin, P. J.: PQC Jun 7
Goldman, I.: EM Jun 55
Goldstein, H.: ANE Jun 142
Goldstone, L. O.: AP Jul 274, Oct 307; MTT Apr 213
Golomb, S. W.: CT May 176; IT May 176
Gonzales, C.: VC Sep 83
Goodrich, R. F.: AP Jul 213, Dec S28
Gordon, E. S.: BTR Dec 8
Gordon, J.: VC Apr 74
Gorozdos, R. E.: AC Dec 46
Goubau, G.: AP Dec S140
Goudet, G.: MTT Jul 327
Graham, M.: EC Dec 479
Graham, R. H.: NS Dec 16
Grasberg, A. G.: E Jun 94; EM Mar 31
Gray, C. L.: AP Jul 281
Green, H. D.: ME Dec 277

Green, J. H.: VC Apr 74
Green, M.: CS May 47
Greenleaf, R. K.: EM Mar 19
Greifinger, C.: ED Jul 288
Grimm, H. J.: I Dec 97
Grinich, V. H.: EC Jun 108
Groginsky, H. L.: ANE Sep 111
Grosswald, E.: CT Dec 334
Guilford, E. C.: E Sep 138
Guillemin, E. A.: CT May 110, IT May 110

H

Haas, I.: EC Jun 108
Hadady, R. E.: SET Mar 14
Haddad, R. A.: AC Nov 121
Hadley, A. M.: CP Sep 175
Haefeli, H. G.: CT May 79; IT May 79
Hall, N. A.: E Apr 43
Halstenberg, R. V.: AC Dec 97
Hamasaki, J.: MTT Jul 360
Hamburger, F., Jr.: E Apr 31
Hammerle, K. J.: IT Mar 9
Handelsman, M.: CS May 31
Hanley, G.: MTT Jan 23
Hansen, R. C.: AP Jul 276, Dec S458
Harary, F.: CT May 59; IT May 95
Hare, M. D.: ED Oct 397
Harken, D. E.: ME Dec 246
Harrington, R. F.: AP Apr 150
Harris, C. M.: AU May–Jun 80
Harris, E. F.: AP Jul 281; VC Apr 2
Harris, L. A.: ED Oct 413
Hartel, R. R.: EC Jun 159
Hartin, W. J.: NS Mar 11
Hartline, H. K.: ME Jun 84
Hartmanis, J.: CT Mar 69
Harvey, A. F.: MTT Oct 402
Harvey, R. A.: NS Dec 20
Hassler, G. L.: ME Mar 52
Hauser, G.: RQC Jun 53
Hawkins, H. E.: ANE Mar 26
Haycock, O. C.: AP Oct 414
Hayes, O. E.: ED Jul 330
Hazel, H. K.: PT Aug 39
Hazony, D.: AC Nov 132
Heald, M. A.: NS Sep 33
Heckelman, T. J.: CS Jun 142
Hedgecock, N. E.: AP Dec S284
Hedrich, A. L.: I Mar 22
Heffner, H.: MTT Jan 83
Heider, E.: AP Apr 201
Held, G.: AP Dec S296
Hellman, R. K.: E Sep 113
Hellstrom, M. J.: BTR May 7
Helstrom, C. W.: IT Sep 139
Helvey, T. C.: SET Jun 57, Sep 99
Henn, W.: AC Dec 116
Hennie, F. C.: CT Mar 35
Henny, G.: ME Jun 75
Herold, E. W.: NE Sep 1
Herrick, J. F.: ME Dec 195, 202
Herrman, G. F.: BTR Dec 75
Herrold, G.: ME Dec 213
Hessel, A.: AP Dec S201
Hewish, A.: AP Dec S120
Heyne, J. B.: RQC Jun 41
Hicks, B. L.: CT Mar 137
Higgins, S. F.: SET Sep 123
Higgins, T. J.: AC Dec 150; ME Sep 125
Hilibrand, J.: EC Sep 287
Hill, R. M.: MTT Jan 73
Hillyard, L. R.: E Mar 10
Hoadley, G. B.: E Sep 122
Hobbs, E. W.: CT Mar 135
Hoch, O. L.: ED Jan 18
Hodder, W. K.: SET Sep 117
Hoehndorf, F.: MIL Oct 162
Hoffman, R. A.: MIL Oct 160
Hoffman, W. C.: AP Dec S301
Hoge, R. R.: IE Jan 38; NS Jun 42
Holland, D. B.: ME Sep 125
Holland, G.: CS Sep 180
Hollis, J. L.: CS Sep 185
Holt, S. F.: AP Oct 434
Honey, R. C.: AP Oct 320
Hoover, G. W.: PT Aug 23
Horowitz, I. M.: AC Dec 5; CT Sep 296
Horsting, C. W.: ED Jan 119
Hosono, T.: MTT Jul 370
Hougardy, R. W.: AP Jul 276
Houseman, E. O., Jr.: MTT Oct 475
Howarth, D. J.: CP Jun 81
Hoyt, W. M.: E Mar 10
Hsieh, H. C.: AC Nov 16, Dec 212
Hu, M. K.: AP Oct 373
Hu, Y. Y.: AP Oct 373
Huang, C.: ED Apr 141, 154
Huber, J. C., Jr.: AP Jul 281
Hudson, A. C.: MTT Apr 277
Hudson, W. T.: E Mar 10
Huffman, D. A.: CT Mar 4, May 41; IT May 41
Hufnagel, C. A.: ME Mar 13
Huggins, W. H.: AC Nov 91
Hughes, H. E.: ED Jul 311
Hull, J. L.: PT Aug 50
Hupert, J. J.: CT Sep 292
Hyneman, R. F.: AP Oct 335

I

Iden, F. W.: ANE Jun 100
Igleheart, J. C.: CS Sep 173
Iizuka, K.: AP Oct 386
Ikegami, F.: AP Jul 252
Ikeno, N.: CT May 187; IT May 187
Ingram, S. B.: E Apr 58
Inouye, G. T.: MIL Oct 178
Isley, C. T.: IT Sep 139, Dec 186
Ivey, H. F.: ED Apr 203, Jul 335

J

Jackson, H. G.: NS Jun 64
Jackson, W. E.: ANE June 85
Jacobsen, A. B.: PT Aug 28
Jacobson, B. S.: ME Jun 66
Jacobson, E. D.: ME Sep 116
Jacobson, M. J.: IT Mar 4
Jameson, W. P.: MIL Jul 105
Jamison, J. H.: EC Dec 432
Janos, W. A.: IT Jun 67
Jaynes, E. T.: IT Sep 98
Jewett, R. H.: MIL Jan 12
Jewett, W. M.: CS May 7
Jochim, K. E.: ME Dec 232
Johler, J. R.: AP Jan 1
Johnson, C. C.: ED Jan 6, Apr 189, Oct 409
Johnson, C. M.: MTT Jan 27, Apr 229
Johnson, C. W.: ME Sep 134
Johnson, L. J.: CP Dec 259
Johnson, P.: ME Dec 287
Johnson, R. C.: MTT Jul 374
Johnston, C.: VC Sep 24
Johnston, L. B.: BTR May 54
Johnston, T. W.: AP Dec S337
Jones, E. M. T.: MTT Jan 128, Oct 453
Jones, H. C.: RQC Jun 16
Jones, R. E.: ME Jun 92
Jordan, E. C.: AP Jan 87
Jordan, W. F., Jr.: ED Jan 79
Junga, F. A.: NS Jun 49
Jury, E. I.: AC May 15

K

Kahn, L.: CP Sep 150
Kahn, W. K.: MTT Jan 102, Oct 430
Kalaba, R.: AC Nov 1; CT May 271; IT May 271
Kalman, R. E.: AC Dec 20, 110, 112
Kamenetsky, M.: MIL Jul 75
Kane, W. E.: RQC Jun 34
Kantrowitz, A.: MIL Apr 34
Kaplan, L. J.: MTT Apr 298, Jul 392, Oct. 473, 475
Karal, F. C., Jr.: AP Dec S91
Karbowiak, A. E.: AP Dec S191
Karp, S. N.: AP Dec S91
Karr, P. R.: IT Mar 33, Sep 140, Dec 186
Katsura, S.: ME Dec 283
Katz, A.: EM Sep 75
Kawahashi, T.: MTT Apr 247
Kay, A. F.: AP Jan 22, 32
Kay, I.: AP Jan 11, Dec S255
Kazarinoff, N. D.: AP Dec S21
Kear, F. G.: ANE Jun 61
Kearney, J. W.: E Jun 67
Keen, A. W.: CT Jun 188
Keilson, J.: IT Jun 75, 77
Keller, E. A.: IE Apr 35
Keller, J. B.: AP Apr 146, Dec S52, S87
Kelley, L. C.: CS Sep 167
Kenna, L. A.: EM Jun 49
Kennedy, W, F.: SET Sep 138
Kent, G.: CT Dec 388
Kenyon, R. J.: MTT Jul 391
Kessler, E., III: ANE Mar 31
Keys, J. E.: AP Dec S77
Kie , K. M.: CS Jun 125
Kilmer, W. L.: E Jun 85; EC Sep 321
Kim, C. S.: BTR Dec 83
Kim, W. H.: CT May 71, Jun 219, Sep 267; IT Jun 62; AC Dec 108
King, D. D.: MTT Apr 229
King, E. N.: PT Jun 18
King, H. E.: AP Apr 197
King, R.: AP Jan 53, Dec S440
Kingston, R. H.: MTT Jan 92
Kintner, P. M.: EC Jun 227
Kirkpatrick, J.: ME Jun 82
Kirschbaum, H. S.: MTT Jan 142
Klante, K.: AP Dec S68
Klapper, J.: AU May–Jun 80
Klein, J. J.: AC Nov 182
Klein, R. J.: VC Apr 13
Kleinman, R. E.: AP Jul 213
Kline, D. F.: E Apr 38, Jun 108
Klipsch, P. W.: AU Mar–Apr 34, Jul–Aug 93, Nov–Dec 161
Knight, T. G.: CS Sep 209
Knudsen, H. L.: AP Dec S361
Knudsen, H. K.: AC Nov 112
Ko, W.: ED Jul 341
Koch, J. W.: CS Jun 77
Kochenburger, R. J.: AC Dec 59
Kodis, R. D.: AP Dec S468
Koenig, H. E.: E Sep 128
Kogo, H.: MTT Jul 393
Kohno, S.: MTT Jul 370
Kolff, W. J.: ME Mar 7
Kolodkin, S. S.: SET Mar 47
Konrad, M.: NS Mar 35
Kosmahl, H. G.: ED Apr 225
Kosonocky, W. F.: EC Sep 277
Kouyoumjian, R. G.: AP Dec S273, S379, S406
Kranc, G. M.: AC Dec 108
Krassner, G. N.: CS Dec 232
Krendel, E. S.: ME Sep 149
Kroll, N.: EC Sep 307
Kudravcev, V.: ME Dec 267
Kuether, F. W.: ME Dec 286
Kummer, W. H.: AP Oct 428
Kunze, A. A.: CS Dec 241
Kuo, F. F.: CT Mar 131
Kurokawa, K.: MTT Jul 360
Kurshan, J.: EM Mar 14

L

Ladd, A. W.: CS Jun 102
Ladd, D. W.: EC Mar 36
Lai, D. C.: AC Nov 91
Lakin, J. R.: E Apr 50
Lambert, L. M.: EC Dec 470
Lambert, V. L.: EM Mar 8
Landy, J. J.: AC Dec 81
Lane, J. A.: MTT Jan 177
Lane, W. V.: PT Aug 12
Langberg, E.: CS Jun 68
Lange, A. S.: AC May 21
Lanzkron, R. W.: AC Dec 150
La Plant, O.: ANE Mar 26
La Rosa, R.: CT Mar 95
Lass, H.: IT Sep 138
Latimer, K. E.: CP Jun 62
Leadabrand, R. L.: AP Apr 127
Lebenbaum, M. T.: E Jun 67
Ledley, R. S.: EC Jun 131, 230
Lee, H. E.: BTR May 25
Lee, L. K.: PT Jun 22
Lee, R. C.: EC Jun 186
Leipnik, R.: IT Dec 184
Leith, E. N.: AC Nov 137
Leondes, C. T.: AC Nov 16, 100, Dec 212
Lerner, R. M.: CT May 197; CP Dec 263; IT May 197
Lesk, I. A.: ED Jan 28
Levadi, V. S.: AC Nov 55
Levey, L.: MTT Jan 102
Levin, E.: AP Apr 142
Levine, A.: IT Jun 90
Levine, D.: AC May 69
Levine, M. B.: IE Dec 26
Levis, C. A.: AP Dec S424
Levy, B. R.: AP Dec S52
Levy, E. C.: AC May 37
Lewin, L.: AP Apr 162
Lewis, C. H.: CP Sep 144
Lewis, D. J.: MTT Jan 110
Li, T.: AP Jul 223
Li, Y. T.: IE Dec 57
Lin, G.: ME Dec 277
Lin, H. C.: CP Dec 269; ED Jan 79
Linden, D. A.: CT Sep 323
Lindorff, D. P.: AC Dec 173
Lineweaver, J. L.: ED Jan 118
Litchford, G. B.: ANE Jun 118
Lo, A. W.: EC Sep 277
Lock, J. M.: CP Jun 93
Lofgren, L.: CT May 158; IT May 158
Loh, S. C.: AP Jan 46, Jul 226
London, F. H.: IE Jan 31
Lory, H. J.: AC Nov 91
Losee, F. A.: CS Jun 102
Lucal, H. M.: EC Dec 449
Luebke, W. R.: ED Jul 294
Luedicke, E.: BTR May 33
Lukatela, G. L.: IE Jul 40
Lunelli, L.: CT Dec 392
Lutz, S. G.: CS Jun 102

M

Macdonald, J. R.: AU Sep–Oct 128
Mack, D. A.: NS Jun 64
Mackay, R. S.: ME Jun 100
Maclean, T. S. M.: AP Dec S379
MacPherson, A. C.: ED Jan 83; I Sep 44
MacWilliams, F. J.: CT Mar 135
Madden, R.: ANE Dec 219
Madich, P.: EC Jun 182
Madrid, D. C.: SET Jun 73
Maffett, A. L.: AP Jul 213
Mager, R. F.: E Jun 104
Maher, T. M.: AP Apr 199
Makow, D. M.: ANE Sep 222; I Mar 32
Mangiaracina, R. S.: MTT Jan 11
Manke, A. G.: VC Apr 47
Mann, P. A.: AP Oct 353
Marcus, M. B.: IT Dec 179
Marcus, R. S.: IT Mar 12
Marcus, S. M.: EC Jun 98
Marden, E.: ME Sep 167
Margolis, M.: AC Nov 100
Marie, P.: AP Dec S412
Markham, A. S.: ANE Mar 4
Martin, A. V. J.: CS May 57
Martin, M. A.: SET Mar 33
Martinek, J.: ME Sep 112
Martinengo, R.: BTR Dec 31
Maslen, S. H.: MIL Apr 52
Mason, H. L.: ME Sep 167
Mathews, M. V.: IT Sep 129
Matsumaru, K.: MTT Jan 175, Apr 192
Matthaei, G.: MTT Oct 453
Matthews, L. E.: BTR Jan 22
Matzek, T.: BTR Jan 18
Mayeda, W.: CT Mar 136, Dec 394
McAuliffe, G. K.: CS Sep 189
McClurg, G. O.: IE Dec 20
McCluskey, E. J., Jr.: EC Dec 439
McConnell, D.: ME Sep 121
McCook, R. D.: ME Dec 234
McCormick, G. C.: AP Dec S288
McFadden, J. A.: CT May 228; IT May 228, Dec 174
McFarlan, R. L.: E Mar 23
McFee, R.: AP Apr 199
McGhee, R. B.: AC Dec 199; IT Jun 90
McGregor, J. E.: PT Sep 30
McGregor, R. R.: ME Mar 51
McKain, J. L.: AU Jul–Aug 101
McLay, A. B.: AP Dec S284
McLean, J. D.: EM Sep 71
McMillan, S. H.: IE Jan 34
McPhee, K. H.: CP Mar 3
McRae, D. D.: SET Jun 61
Meagher, R. E.: EC Sep 263
Medd, W. J.: MTT Jul 395
Meixner, J.: AP Dec S435
Melchor, J. L.: MTT Jan 15
Melmed, A.: EC Dec 474
Melngailis, I.: RFI May 11
Mermin, N. D.: IT Jun 75, 77
Metcalfe, D.: CS Dec 272

Metz, H. I.: ANE Jun 78
Metze, G.: CT Mar 5
Meyer, D. R.: ME Sep 121
Michaelson, H. B.: EWS Dec 89
Mickelson, N. B.: MIL Jul 69
Mickelwait, A. B.: MIL Oct 149
Middleton, D.: CT May 234; IT May 234, Jun 86
Mihran, T. G.: ED Jan 54
Mikelson, W.: AC Dec 21
Miller, F. B.: IE Jul 3
Miller, G. L.: EC Dec 479
Miller, N. D.: CS Dec 249
Miller, R.: BTR Jan 5
Miller, R. E.: CT Mar 5
Milligan, J. V.: ME Dec 274
Milnes, A. G.: E Mar 6; ED Apr 125; EC Dec 458
Mine, H.: CT May 138; IT May 138
Mishkin, E.: AC Nov 121
Mitchell, J. F.: VC Sep 20
Mittra, R.: AP Dec S244
Miyata, J. J.: EC Jun 159
Moglia, G. A.: PT Jun 29
Montgomery, L. H.: ME Mar 29
Montgomery, P. O'B.: ME Sep 186
Montgomery, R. A.: MIL Jan 12
Mood, A.: RQC Jun 16
Moore, G. E.: E Jun 82
Moore, R.: ME Sep 171
Morgan, S. P.: AP Oct 342
Morgan, W. L.: EC Jun 148
Morgan-Voyce, A. M.: CT Sep 321
Morgenthaler, F. R.: MTT Jan 6
Morris, R. M.: BC Feb 22
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Sample cell used at the IBM Watson Laboratory for studies of the self-diffusion of quantum liquids.

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Experiments on the pure quantum liquid revealed diffusion persisting to the lowest temperatures. However, it was apparent that the diffusion was not thermally activated as in an ordinary liquid, or in a gas. Diffusion persisted for two reasons: (1) because of the zero-point energy of the atoms, and (2), because of the atoms' long wave length as compared with the thickness of the potential barriers which inhibited their motion. The results of the experiments on dilute solutions of He^3 in He^4, in accord with expectations, showed that the He^3 diffusion coefficient increased rapidly with decreasing temperature.

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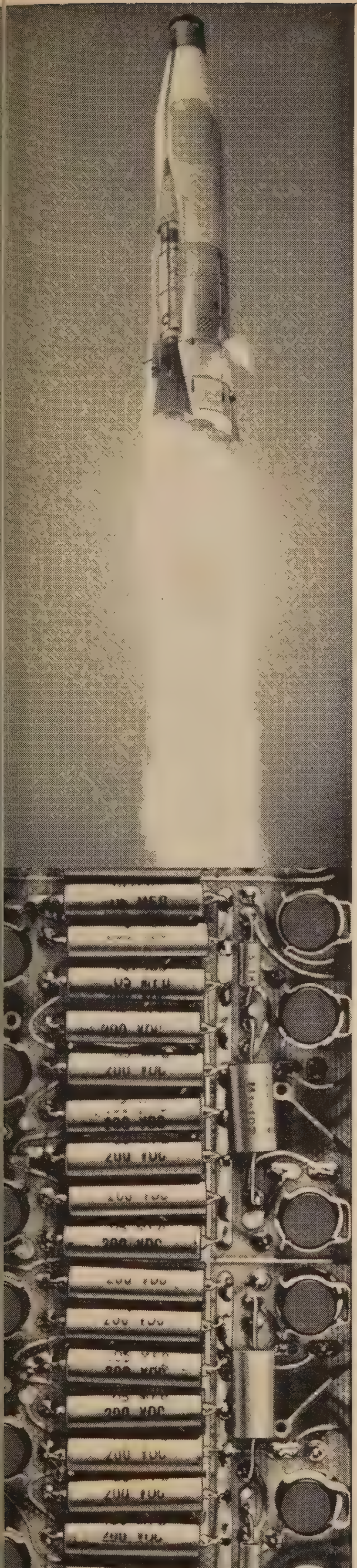

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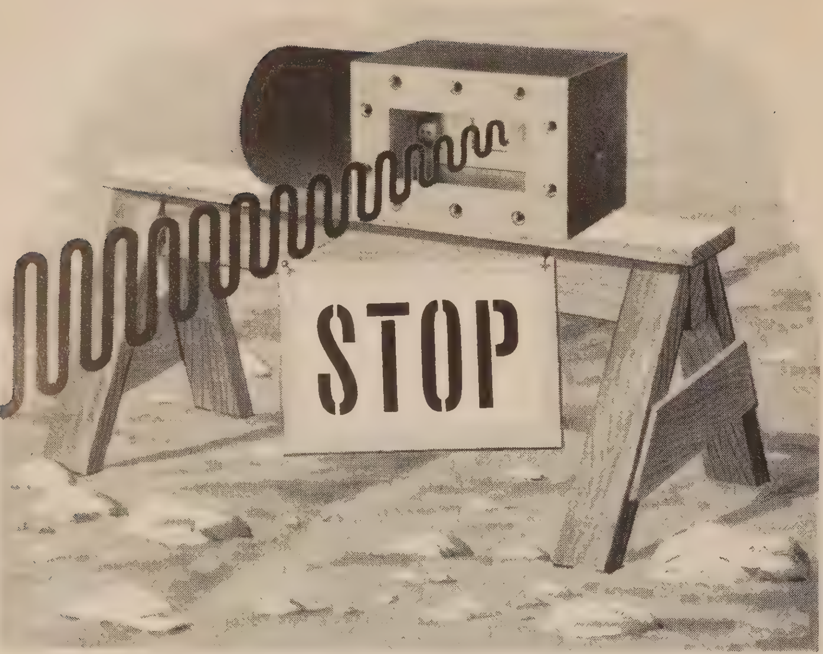

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X	MA-710	8.5-9.6 kMc	30 db min.	0.2 db max.	1.10 max.
X	MA-750*	8.5-9.6 kMc	30 db min.	0.2 db max.	1.10 max.
Ku	MA-760	16.0-17.0 kMc	30 db min.	0.2 db max.	1.10 max.
Ku	MA-776**	16.0-17.0 kMc	75 db min.	0.2 db max.	1.10 max.
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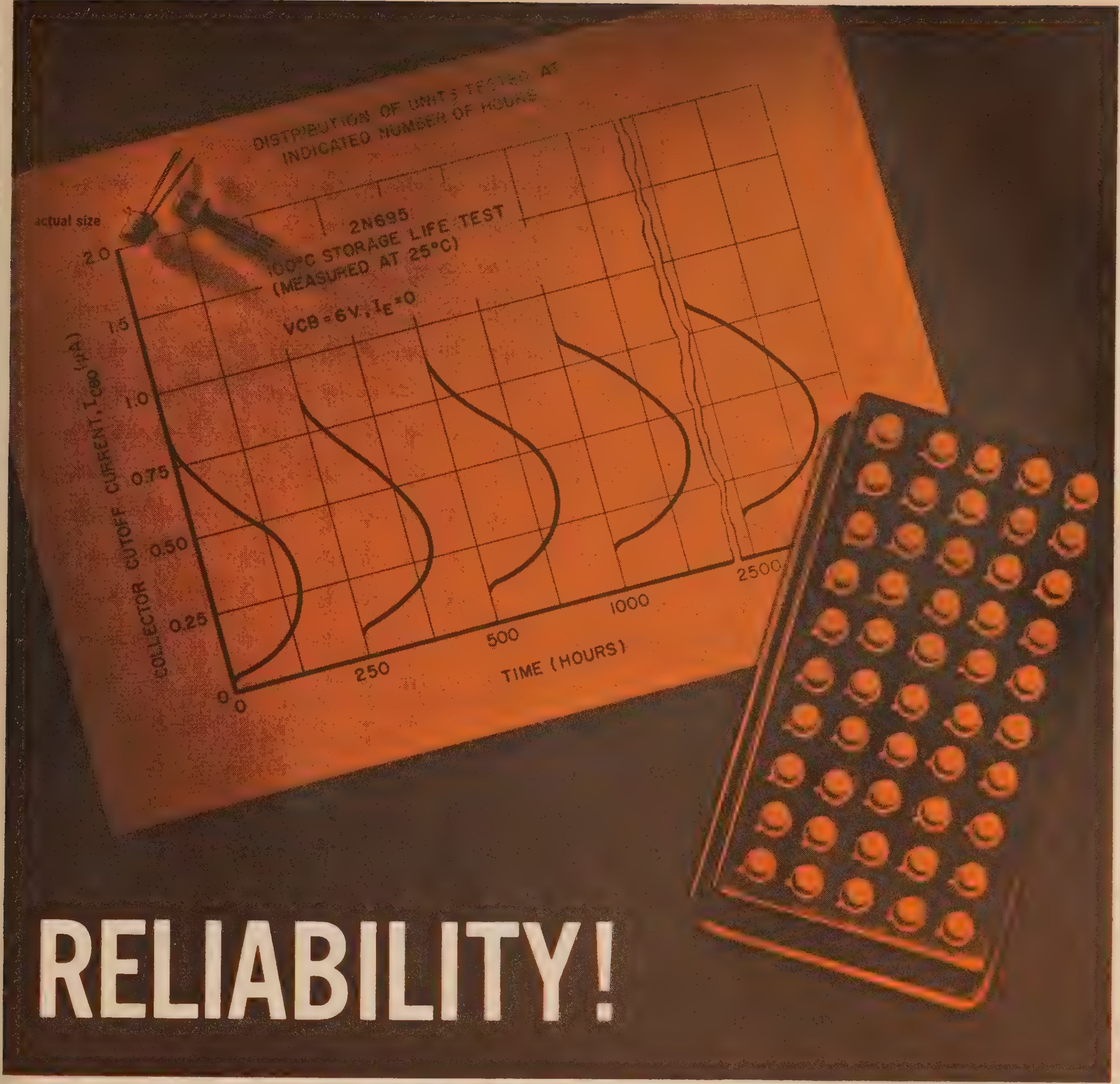
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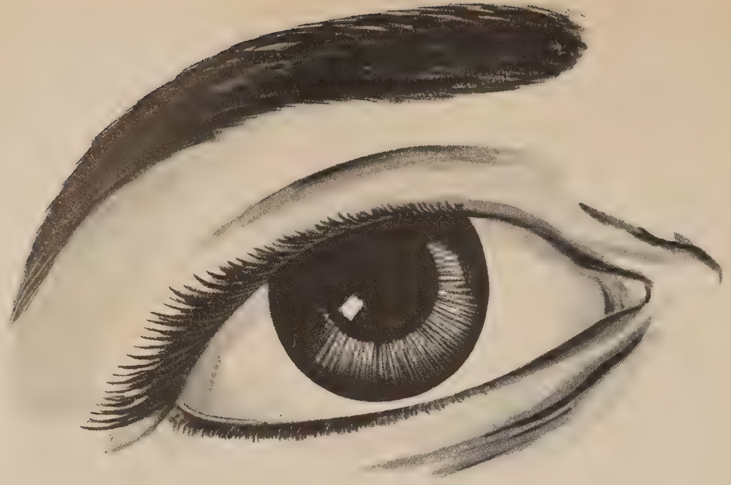

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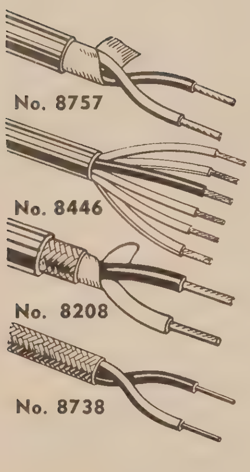

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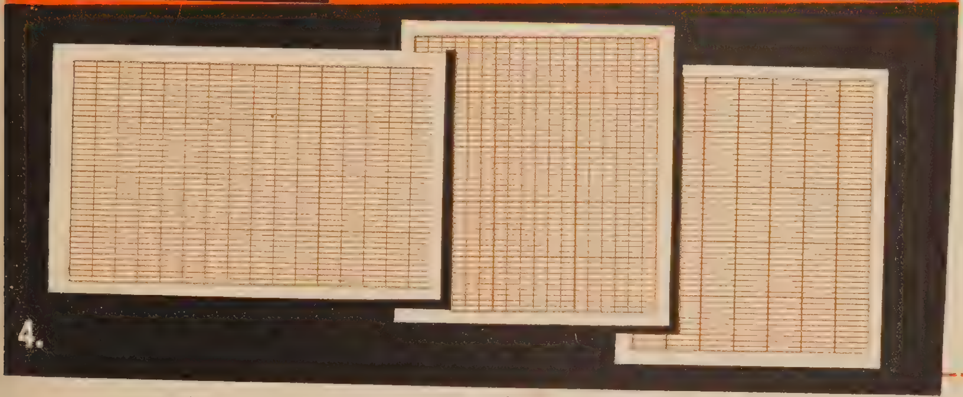
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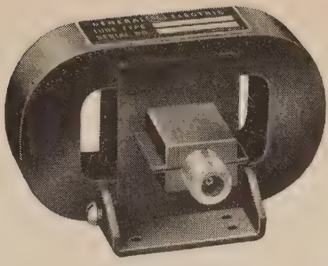
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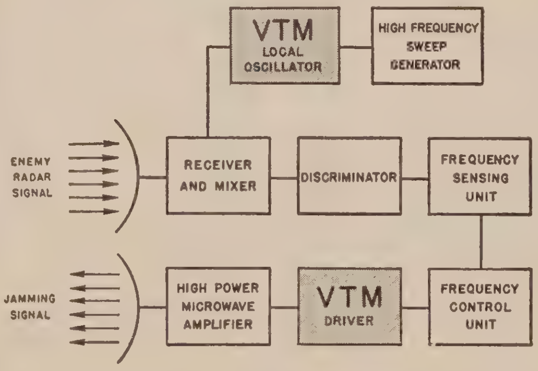
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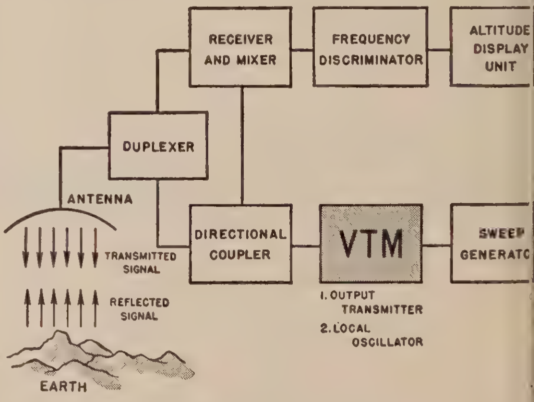
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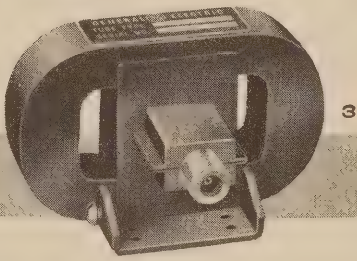

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CRYSTAL FILTERS

Within three years Hermes Electronics Co. has become the nation's leading producer of frequency selective devices utilizing piezoelectric crystal resonators. The growing demand for crystal filters and related devices has created a number of career opportunities for: Circuit Design Engineers, Crystal Physicists, and Network Theory Specialists.

Hermes Electronics Co. is a unique organization where responsibility and initiative are encouraged. Here you will also find the stimulation and environment of a young and growing company. Your association will be with staff members who are in the vanguard of many of today's rapidly expanding technical frontiers.

Salaries and other benefits are comparable to those of major research and development organizations. The company's location in Cambridge, Mass. affords unequaled cultural, living, and recreation facilities.

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Interested scientists and engineers are invited to address inquiries to: Mr. E. E. Landefeld, Personnel Director.

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Positions Open

The following positions of interest to IRE members have been reported as open. Apply in writing, addressing reply to company mentioned or to Box No. ....

The Institute reserves the right to refuse any announcement without giving a reason for the refusal.

Proceedings of the IRE
1 East 79th St., New York 21, N.Y.

ELECTRONIC ENGINEER

Young Electronic Engineer, experienced in circuit design, to work as assistant to one of the outstanding engineers in the country in the design and development of precision analog equipment. This is once-in-a-career opportunity for the right individual to learn from one who has, over the past 15 years, established a proven record of accomplishment in the analog field. Apply Milgo Electronic Corp., 7620 N.W. 36th Ave., Miami 47, Florida.

STAFF OPENINGS—ELECTRICAL ENGINEERING DEPT.

Staff openings for September 1960 in Electrical Engineering Dept. Mostly undergraduate instruction. Attractive salary, living conditions. Recreation center of the West. Correspondence invited. I. J. Sandorf, Chairman, Dept. of E.E., University of Nevada, Reno, Nevada.

PROFESSOR

The University of Alaska has an opening for an Assistant Professor of Electrical Engineering—to teach and do research on the ionosphere, the aurora, or on problems in communications or power in the North. Industrial experience or advanced degree required. Write Airmail to Dept. of E.E., University of Alaska, Box 497, College, Alaska.

RESEARCH ENGINEER

Engineering or Physics degree. 5-10 years experience in inertial guidance systems and/or components. Aid in developing concepts of advanced guidance systems and in promulgating written and verbal communications on the subject to other groups in allied fields. Send resume to G. A. Nesbet, Litton Industries, Beverly Hills, Calif.

RESEARCH SCIENTIST

Physics degree, advanced preferable. Experienced in thermodynamics, cyrogenics, vacuum technology, optics. Aid in developing space stimulation techniques. Send resume to G. A. Nesbet, Litton Industries, Beverly Hills, Calif.

ENGINEERING EDITOR

Young engineer with an interest in technical publications work has an excellent opportunity for a permanent position on the IRE headquarters staff as assistant to the Managing Editor. Send resume to E. K. Gannett, Managing Editor, Institute of Radio Engineers, 1 East 79 Street, New York 21, N. Y.

TEACHING POSITION

Expanding, recently organized dept. with a modern science-oriented curriculum, seeks a well-qualified person who is interested primarily in teaching. Advanced degree required. This is an unusually attractive position for the right individual. 12 month salary assured, if desired for approximately 10½ months service. Possible to have every other summer off while earning full salary. Salary range is approximately

(Continued on page 118A)

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We are seeking an engineer with a record of outstanding achievement in research and development to direct the activities of our Computer Systems Section. As supervisor of this important activity, you will have the opportunity to develop research programs of greatest appeal to you and your staff in the following areas:

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- Advanced Development
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  - Logic
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As a Foundation staff member you will be joining a mature, independent research organization with a staff of over 600 engineers and scientists contributing to a wide variety of military and industrial research programs.

You will receive a competitive salary plus liberal insurance and retirement benefits in addition to four weeks vacation after one full calendar year of service. Our location in a major midwestern city offers excellent cultural and recreational opportunities.

If this is the unusual professional opportunity you have been looking for, reply in confidence to:

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Armour Research Foundation
of Illinois Institute of Technology
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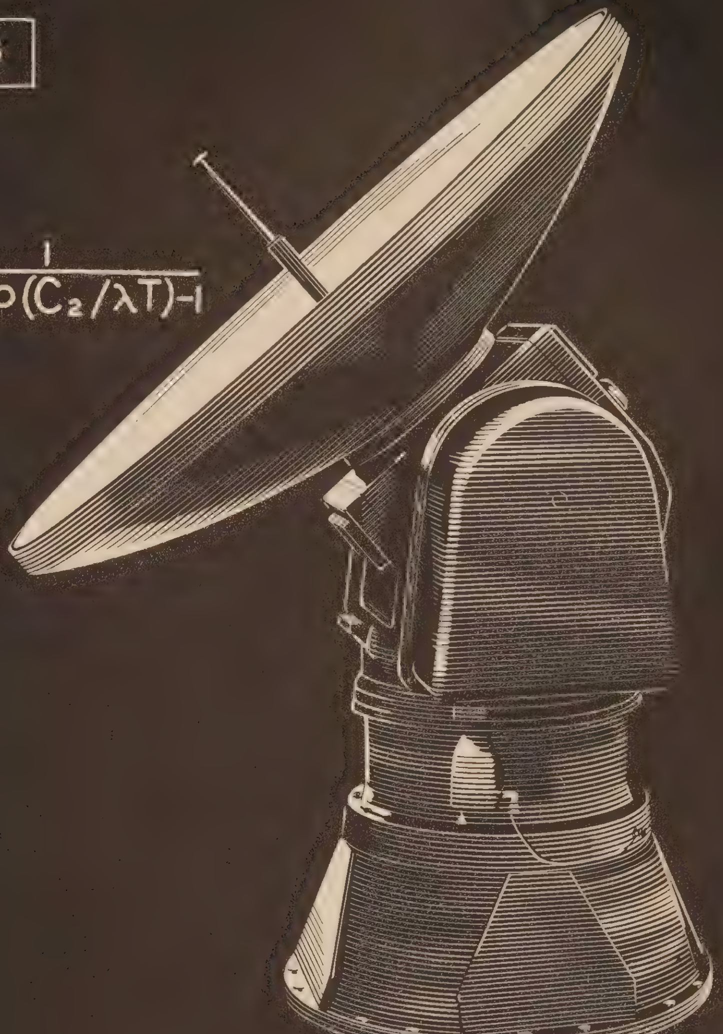
$$C_1 = 8\pi hc$$

$$C_2 = \frac{hc}{k}$$



THE UNUSUAL SHAPE OF PROGRESS

The principles of spectral energy distribution of the radiation from a black body, announced by Max Planck in 1900, were of intense interest to the theoretical physicists of the day. Since then, these principles have paved the way for major advances in marine navigation and radio astronomy. For example, Collins new Radio Sextant pictured here is capable of continuously tracking the sun or the moon under any weather conditions, furnishing both the ship's location and heading with high precision.

Max Planck's work was done in an atmosphere of unrestricted scientific freedom. Such an atmosphere is provided in Collins Radio Company Research laboratories for physicists, mathematicians and engineers engaged in basic research. These are men capable of looking beyond man's present limitations, with the ability and ambition to analyze man's progress and envision his future environment. To further implement the advancement of scientific knowledge at Collins, with the resultant development of new technologies, unique professional opportunities are now being offered in the fields of radio astronomy, circuits, advanced systems, antennas and propagation, mechanical sciences and mathematics. Your inquiry is invited.

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NOW—CHOOSE YOUR ASSIGNMENT AND LOCATION THROUGH OUR NATION-WIDE PLACEMENT SERVICE

SALARIES $7,500 TO $18,000

We can offer you a large selection of diversified positions with America's foremost electronic organizations. Some positions for non-citizens.

The following are just a few of a large number of desirable opportunities.

SR. ENGR.—DIGITAL COMPUTERS— Exp. required in systems, logical design, packaging, system integration or pulse circuitry. To $15,000

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RF ANTENNA—Proj. Engr. $15,000

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Just tell us what you would like to do and where you would like to locate, and we will handle everything for you without cost or obligation.

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☐ Northern East Coast
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POSITION DESIRED

☐ Systems
☐ Radar
☐ Transistors
☐ Tubes
☐ TV Receivers
☐ Microwave
☐ Anal. Computers
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☐ Servo-Mechanisms
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☐ Components
☐ Circuit Design

WHAT SATISFIED ENGINEERS SAY:

Dear Mr. Brisk:
This is to advise you I have accepted employment with ———— Company as a project leader at $15,000.
Your service has been a real help to me, for I am sure I could not have found this unusual opening by myself.
Thank you.
H.M.P.

Dear Mr. Brisk:
I have today advised ———— Company that I would be pleased to accept their offer. I start August 1st as a senior engineer at $13,000.
The opportunity is one of the most outstanding I have seen.
J.S.E.

A National Electronic Placement Service Established in 1937.
You are assured of prompt and completely confidential service by forwarding three resumes to* HARRY L. BRISK, *(Member IRE)

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Positions Open

(Continued from page 116A)

$6,000 to $8,000. Private, medium-sized university in midwest. Send complete resume to Box 2011.

ENGINEER

Electronics Research and Development Lab. needs man with experience in transistor-circuit development. Position carries opportunity to study for advanced degrees in Physics or Engineering. Salary consistent with training and experience. Applicants will be required to have BS. degree or better in Physics or Engineering to qualify. For more details write Research Foundation, Oklahoma State University, Stillwater, Okla., or call R. F. Buck, FRontier 2-6211, Ext. 579, after 5 P.M. or holidays call FRontier 2-8480.

ELECTRICAL ENGINEERS

University appointments Electrical Engineering. Three openings including the Chair in Electrical Engineering in new Faculty of Applied Science with opportunity for advancement and research. Attractive salary schedule. New building under construction. Ph.D. or Master's degree desirable. Apply to F. A. DeMarco, Principal, Essex College, Windsor, Ontario.

TEACHING POSITION

Expansion of graduate work in E.E. at Syracuse University has created several opening at the Assistant and Associate Professorial ranks. Except in very unusual circumstances, applicants should have a Doctorate in E.E. or a closely allied field. Opportunities exist for combination of teaching and research during the academic year, and for summer employment on research. Teaching is primarily at the graduate level. Salary depends on experience, but in most cases the yearly salary (for 11 months work) is reasonably competitive with industry. Write to Dr. W. R. LePage, Chairman, Dept. of E.E., Syracuse University, Syracuse 10, New York.

ASSOCIATE OR ASSISTANT PROFESSOR

Expert in field of semiconductors. Ph.D. is minimum requirement, applicant must have some teaching experience. Academic rank and salary dependent on demonstrated ability and over-all experience. The man in this position will divide his time between teaching and research. Appointment begins Sept. 1960. Write, including resume to W. R. Beam, Head, E.E. Dept., Rensselaer Polytechnic Institute, Troy, N. Y.

EDITOR

Scientific book publisher needs radio engineer to plan and develop new books. Publishing experience desirable. Write in detail. State salary. Box 2012.

ENGINEERS

Major firm seeking (1) Section leader, Electromechanical design, (2) Section leader, testing and reliability, knowledge of Military acceptance testing, (3) Manufacturing engineers, knowledge of standards, process and tool engineering for electromechanical display equipment. Top future positions. Benefit programs. Salaries $8,000–$15,000. Contact Mr. W. Hart, Witty-Polon Management Consultants, 176 East 75 St., New York 21, N. Y. Telephone: Lehigh 5-4222.

INSTRUCTOR AND ASSISTANT PROFESSOR

For those interested in teaching fundamental electrical & electronic subjects. Opening for fall semester beginning Sept. 1960. Salary depends

(Continued on page 120A)

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Before you make your career decision, you should hear the story that is now unfolding at the Baltimore Divisions of Westinghouse. Get the facts on the exciting programs now under way . . . including advanced development work on new weapons systems with revolutionary data processing, antenna systems, and system synchronization. If you are beginning or continuing your career as an electrical or mechanical engineer, we would welcome the opportunity to give you the facts about career opportunities in the following fields:

MICROWAVE SYSTEMS
SYSTEM SYNCHRONIZATION
SYSTEMS RELIABILITY PREDICTION
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ADVANCED DATA DISPLAYS
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DIGITAL COMPUTER DESIGN
ADVANCED ANTENNA SYSTEMS
ADVANCED SYSTEMS AUTOMATED TEST
TRANSMITTER AND RECEIVER SYSTEM DEVELOPMENT
TRANSFORMER DESIGN

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The **M.I.T. OPERATIONS EVALUATION GROUP** has since 1942 had the responsibility for doing operations research for the Chief of Naval Operations. This group of M.I.T. staff scientists advises the Chief of Naval Operations and certain Fleet and Force commanders on a variety of complex operational problems susceptible to quantitative analysis.

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U.S. Citizenship required

KLYSTRON

To electrically and mechanically design and develop broadband and super high power Klystron tubes.

TRAVELING WAVE DEVICES

To join a development team on high and low powered Traveling Wave Tubes and Carcinotrons.

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To perform advanced research on Crossed Field Amplifiers.

BARRATRON®

To carry on development work on this new and unique microwave product.

MAGNETRON

To perform unique design work in both the CW and Pulse type tube areas.

Openings exist in these product line areas for Junior, Intermediate, and Senior level engineers.

MICROWAVE TUBE ENGINEERS

If you qualify for any of these positions, please contact Mr. Thomas L. Fike, 960 Industrial Road, San Carlos, California.

LITTON INDUSTRIES

Electron Tube Division
San Carlos, California

Positions Open

(Continued from page 118A)

on qualifications. New building and equipment. Opportunity for advancement and further study. 9 month academic year. Part time evening session work available. Health Insurance and Pension Plan. Send complete resume to Prof. I. L. Kosow, Dept. Head. Electrical Technology, Staten Island Community College, 50 Bay St., Staten Island 1, N. Y.

ELECTRICAL ENGINEERING PROFESSORS

Fast growing Engineering School on west coast needs 3 electronic-electrical engineers able to teach circuits and electronics, with a specialty in communications, industrial electronics or computers. MS. degree plus industrial experience is the minimum requirement; a Ph.D. is desirable. Salary and rank will depend on experience. The dept. has just moved into a new building and needs aggressive men who wish to develop curricula and labs. Apply L. Cromwell, Head, E.E. Dept., Los Angeles State College, 5151 State College Dr., Los Angeles 32, Calif.

PROFESSOR

Assistant and/or Associate Professor of E. E. with interest and experience in one of the following areas: electromagnetic theory, information theory, digital computer logic and numerical methods, solid state. Ph.D. required, Combination of reasearch, graduate and undergraduate teaching. Address inquiries to Dr. C. Polk, Head Dept. of E.E., University of Rhode Island, Kingston, Rhode Island.

PROJECT ENGINEER

Project Engineer to supervise complete projects in design and development of automatically sequencing, self checking test equipment used to evaluate complex airborne guidance systems and components, as well as industrial process instrumentation. E.E. plus 5–7 years experience. Kearfott Div.—General Precision, Inc. Att: P. Kull, 1500 Main Ave., Clifton, New Jersey.

SENIOR ELECTRICAL ENGINEER

E.E. degree and 8-10 years experience including experience in electronics. Interesting work in conjunction with a nuclear physics research program. Benefits include a reduced tuition rate for the employee and free tuition for children of employees with 5 or more years of service. If interested, send complete resume, including salary expectations to J. R. Whitley, Employment Supervisor, University of Rochester, 260 Crittenden Blvd., Rochester 20, N.Y.

MEDICAL ELECTRONICS

Biophysical Electronics, Inc. devotes its efforts to the design and manufacture of instruments assisting the physician, psychologist, and research scientist to meet the challenge of preserving and extending life. Positions are open for: Senior Transistor Circuit Designer, Sales and Office Manager and experienced Electronic Technician. Submit resume, availability and salary requirements in first letter to Biophysical Electronics, Inc., New Hope, Pa.

ELECTRONICS ENGINEER OR PHYSICIST

High qualifications and varied experience, particularly in control, rf or nuclear electronics. Appointment as Assistant Professor at $7,000-$8,900 or as Associate Professor at $9,000-$11,700, or to non-academic position at equivalent salaries. To supervise construction of a spiral-ridge cyclotron to produce 50 Mev protons.

(Continued on page 122A)

succeed in '60 with T/I

the careers of these S/C engineers are assured at T/I in '60

DEVICE DEVELOPMENT ENGINEER. *Mission:* Probing the unknown to evolve a variety of new advanced semiconductor-component devices.

CIRCUIT DEVELOPMENT ENGINEER. *Mission:* Discovering through experience and educated imagination, new uses for transistors and specialized semiconductor devices by exploring new frontiers in thought.

Device and Circuit Development Engineers we seek, want liberal freedom of thought and action and advanced physical facilities to permit maximum creative productivity. They desire broad and rapid expansion of their professional horizons with solid financial security and recognition matching personal achievements.

Our Device Development Engineer would be equally intrigued with studies in solid-state diffusion and nuclear radiation experimentation on semiconductor materials and devices. Our Circuit Development Engineer would be productively stimulated by participation in transistorization projects ranging from AM, FM and TV receivers to computer system logic.

You qualify as our Device Development Engineer if you hold a degree in Electrical Engineering, Chemistry or Physics and experience in semiconductor or related development areas. An Electrical Engineering degree and knowledge of transistor circuitry are required for Circuit Development Engineers.

START NOW TO SUCCEED IN '60 AT TEXAS INSTRUMENTS

INTERVIEWS will soon be held in your area. If you qualify for either of these positions, please send a resume immediately to C. A. BESIO, DEPT. 105.

Whether or not you apply now, send for TIPS booklet today and get better acquainted with TI's S-C division.

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SEMICONDUCTOR - COMPONENTS DIVISION
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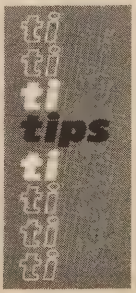

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Semiconductor-Components Division
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Please send me TIPS containing complete information about currently available TI S-C professional careers in my field plus facts on advanced S-C facilities, personnel policies and unique advantages of living in Dallas.

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Join Sanders Associates and combine PLEASANT COUNTRY LIVING with a TOP FLIGHT ENGINEERING CAREER

At Sanders Associates—located in the friendly New England community of Nashua, N.H.—you will find a variety of engineering programs that probe deeply into advanced areas of electronic and electromechanical systems and components for industry and defense.

Here in the fresh clean world of the country, away from the soot, and strain of heavily populated areas, you will discover that Sanders can offer you a wide range of opportunities—at fully competitive salaries.

You will enjoy diversified assignments on technically advanced projects in Radar, ECM, Navigation, ASW systems & devices, Industrial Automation techniques, working with the engineers who originated such products as Panar® radar, Dare target-seeker system, Flexprint® flexible printed circuits, Tri-Plate® microwave products and other Sanders "firsts."

The cost of living is low in Nashua; schools are excellent and attractive homes are available. Downtown Boston is less than an hour away, as are the recreations of mountains, ocean, lakes.

Openings available for:

SYSTEMS ENGINEERS

Through Project Engineer level. Need not be specialists, but must have creative abilities and backgrounds of VHF transmitters and receivers, communications systems in general, data processing techniques, propagation and must be capable of translating this knowledge into complex integrated systems.

RECEIVER DESIGN ENGINEERS

VHF electronically scanned airborne receivers, filters, problems in spurious response reduction and multiplexing.

CIRCUIT DESIGN ENGINEERS

With particular emphasis on transistor application to analog and digital techniques; data handling equipment; audio, video, RF circuitry and switching.

CHIEF MANUFACTURING ENGINEER

10 to 15 years experience in the successful manufacture of complex military electronic systems and instruments

TRANSMITTER & MAGNETIC DESIGN ENGINEERS

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Positions Open

(Continued from page 120A)

Apply to Dr. B. G. Whitmore, Physics Dept., University of Manitoba, Winnipeg 9, Manitoba, Canada.

ENGINEER

To assist in construction of new cyclotron installation. Permanent position. Experience in building and maintaining scientific apparatus essential. Specific experience with cyclotrons desirable. Salary dependent on qualifications and experience. Apply to Dr. B. G. Whitmore, Physics Dept., University of Manitoba, Winnipeg 9, Manitoba, Canada.

TEACHING-RESEARCH, ELECTRICAL ENGINEERS

Expanding university program provides unusual opportunities for positions combining teaching and research. Rank and salary open. Teaching in all E.E. fields. Research primarily in microwave electronics. Apply: Dean E. C. Easton, Rutgers University, New Brunswick, New Jersey.

TEACHING AND RESEARCH

Attractive opening for Electrical Engineer with Ph.D. to help develop graduate program, supervise graduate research and do some teaching. Encouragement given to private research and consultation. Good salary and faculty ranking will be offered to exceptional individual. Position available Sept. 1960 or sooner. Write, Dean, School of Engineering, Vanderbilt University, Nashville 5, Tenn.

ELECTRONIC ENGINEERS

Positions open to Electronic Engineers teaching lecture and laboratory courses in a rapidly growing 4 year college. A background of servomechanisms, circuit analysis, microwaves, and/or transistors is desired. Applications desired from both academic and industrial personnel. Write, Harold P. Skamser, Dean of Engineering, Calif. State Polytechnic College, Kellog-Voorhis Campus, Pomona, Calif.

TEACHER IN ELECTRICAL ENGINEERING

Teacher in E.E. beginning Sept. 1960. One qualified and interested in teaching fundamental undergraduate courses plus one graduate course. Ph.D. or MS. required with salary and rank dependent on qualifications. City location with many industrial contacts. Apply Dept. of E.E., Saint Louis University, St. Louis 8, Missouri.

STAFF ENGINEER

Research engineering position for creative person to form nucleus of a new section in the Electro-physical Labs. Will propose and evaluate new electronic component, circuit and systems concepts. Minimum experience and educational background would be 5 years with at least an MS. in E.E. or Physics. A Ph.D. degree would be preferred with strong interests in electronics, theoretical physics or mathematics. Forward resumes to Mr. R. D. Williams, Employment Mgr., P. R. Mallory & Co. Inc. 3029 E. Washington St., Indianapolis, Ind.

ANALYST

Research and consulting in fields such as transportation, logistics, equipment investment, inventory control, marketing, operations research, data processing. Educational background in economics, transportation, mathematics, statistics, engineering. United Research, Inc., 808 Memorial Dr., Cambridge, Mass. Mrs. Paulsen, Personnel Director.

ELECTRICAL
ENGINEERS
and
PHYSICISTS

INTERESTING &
CREATIVE SENIOR
OPENINGS AT:

THE UNIVERSITY
OF MICHIGAN
Radiation
Laboratory

The Radiation Laboratory's efforts in plasma physics include high density and low density plasmas, using plasma diagnostic techniques for the design of instrumentation to learn about the possible ionospheres of other planets, such as Venus. Analyses of possible plasma radiation from ionospheric trails, shock fronts and flame fronts are being conducted. This work is primarily in theoretical physics.

We are seeking scientists with the Ph.D. degree or with comparable significant experience in the above or closely related fields of research.

Pleasant Mid-West location with liberal fringe benefits. Salary commensurate with abilities and background.

Write sending résumé to:

Mr. C. W. Marlatt

THE UNIVERSITY
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RESEARCH INSTITUTE
Ann Arbor, Michigan

but we can always be good friends, can't we?
CREDIT
CREDIT CARD

To the ELECTRONIC ENGINEER who neglected to MARRY THE BOSS' DAUGHTER:

Don't bother telling us how it happened . . . we almost know. It was Spring—or Fall, no matter—and there you were, alone with That Other Girl. You couldn't have been thinking of your professional future because you'd had to explain to her dad that you didn't drive a locomotive. But she was lovely, desirable and it seemed unthinkable not to share your breakfast Wheaties with her the rest of your days. So, of course, you married her instead of the boss' daughter and your father-in-law turned out to be a grand guy even though he now tells people proudly that you make TV sets or something.

Which pretty much leaves your career up to *you,* doesn't it?

We have some advice for you; we'll not guarantee that it's impartial, but check it for logic anyway: Look for a leading electronics corporation which is essentially an engineering firm, where not only your immediate supervisors but top management will be engineers. Being engineers, they're more likely to recognize ability and to reward achievement *fairly and impartially.* It figures, we think, that where there's an atmosphere of mutual confidence, respect and understanding you'll realize your maximum potential at least a little sooner and more surely.

You may be pretty sure that Bendix, Kansas City, meets the specifications outlined above or instead of mentioning them at all we'd probably follow the crowd by speaking only vaguely of "opportunity" and "challenge." You have criteria of your own . . . measure Bendix with them and let us help you if we may.

P.S. **That girl you did marry will like Kansas City. So will you and the children. Practically everyone does.**

Mail brief confidential resume to MR. T. H. TILLMAN, BENDIX, BOX 303-OX, KANSAS CITY, MO.

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AVIATION CORPORATION
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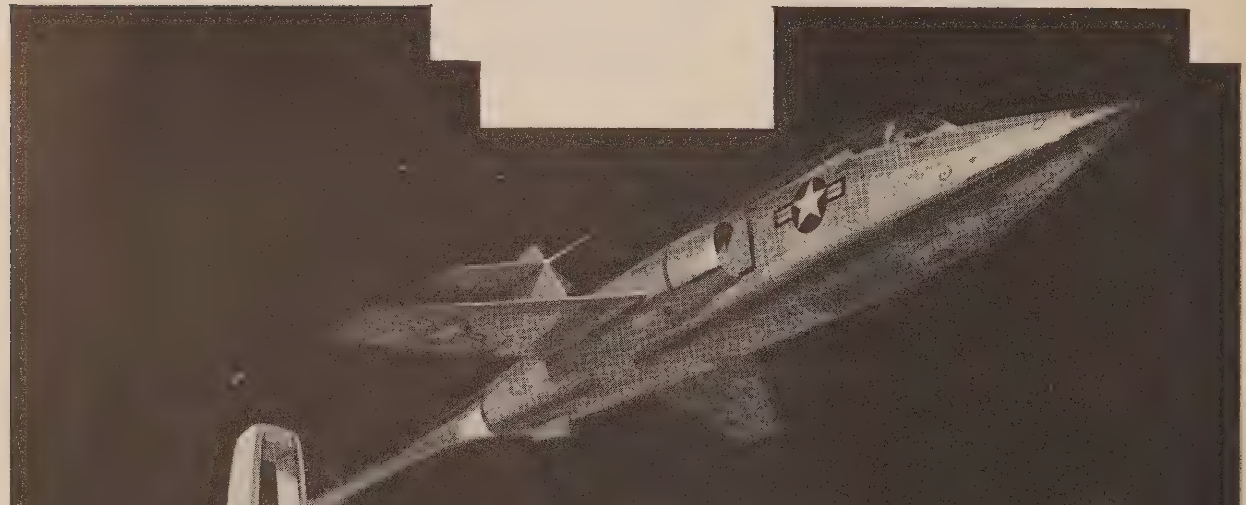
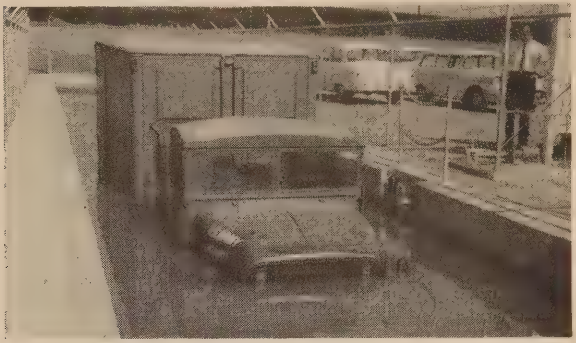
How to thread a needle



The Fording Test *is typical of the tough environmental tests imposed upon advanced electronic equipment designed and produced by Hughes Fullerton engineers.*

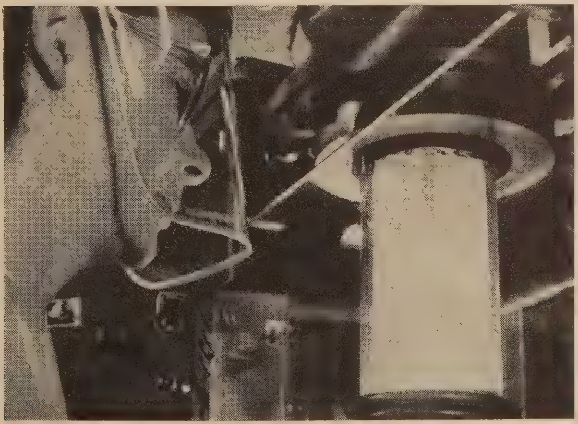


in the dark

TARAN (Tactical Attack Radar and Navigator) is typical of the important new electronic systems developed by Hughes—in an atmosphere famed for its engineering orientation.

Hughes engineers have designed this system to enable pilots to fly blind at very low altitudes in any kind of weather—and actually deliver any kind of armament at tactical targets.

TARAN's amazing abilities are based on several major electronic advances developed by Hughes engineers: A radar system with several times the range and azimuth resolution of current radars. An Automatic Navigation and Display System which pinpoints position continuously and automatically corrects for any navigational deviations. A unique terrain clearance indication warns the pilot of any obstacles when flying at low altitudes. A radar antenna utilizing electronic rather than mechanical lobing.



Molten Ladle *of silicon is watched during first step in the precise manufacture of Hughes semiconductors, just one of the Hughes commercial activities.*

Other Hughes activities provide similarly stimulating outlets for creative engineers. A few representative project areas include: advanced data processing systems, molecular electronics, advanced 3-D surface radar systems, space vehicles, nuclear electronics, ballistic missiles, infrared devices—and a great many others. The commercial activities of Hughes have many interesting assignments open for imaginative engineers to perform research, development, manufacturing of semiconductors, electron tubes, and microwave tubes.

Whatever your field of interest, you'll find Hughes' diversity of advanced projects gives you widest possible latitude for professional and personal growth.

Newly instituted programs at Hughes have created immediate openings for engineers experienced in the following areas:

- Electroluminescence
- Infra-red
- Solid State Physics
- Digital Computers
- Reliability & Quality Assurance
- Systems Design & Analysis
- Equipment Engineering
- Microwave & Storage Tubes
- Communications Systems
- Inertial Guidance
- Field Engineering
- Circuit Design & Evaluation

Write in confidence to Mr. R. A. Martin
Hughes General Offices, Bldg. 6-E4, Culver City, Calif.

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Culver City, El Segundo, Fullerton, Newport Beach,
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SENIOR MICROWAVE ENGINEER

You will be given system responsibility for the development of new concepts in the generation, propagation and radiation of microwave power for heating, cooking and curing purposes, in numerous commercial and industrial applications. (Raytheon is one of the few electronics companies whose staff includes systems, advanced development, and design engineers in these fields).

You must have a BSEE or equivalent and should have 8 years of broad design or advanced development experience in the microwave field in order to handle the planned assignments. (Experience in radar development, for instance, or DC power generators or magnetrons.) Since we're looking for an exceptional individual—who will be rewarded accordingly—the deciding factor will probably be your creativeness and ingenuity, as evidenced by: patent disclosures; significant publications; or descriptions of accomplishments not formalized by patents or publication.

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B.S. in physics, graduate work in E.E.; 7½ years experience in electronics of which 3½ years is in commercial data processing. Have published articles and hold patents in electronics. Desires overseas position. Box 2053 W.

ENGINEER

BSEE., extensive antenna and R.F. experience, design and project supervision. Broad background includes sales and engineering management, contract negotiations. Desires position as General Manager of antenna company, or participant in ownership management of antenna consulting firm or small growing company. Box 2054 W.

COMPONENTS ENGINEER

E.E. degree. 10 years solid experience in electromechanical components—development, evaluation, application and standardization. Desires a challenging, responsible position in a supervisory capacity, New York, Long Island area preferred. Box 2055 W.

ELECTRONIC FIELD ENGINEER

Graduate engineer, BSEE., several years experience, age 32, fair health, seeking position as electronic engineer—sales engineer, field engineer, coordinator customers' technical requirements either commercial or military customers, or supervisor equipment installation and installation checkout. Preparation with company training course desirable. Box 2056 W.

(Continued on page 128A)

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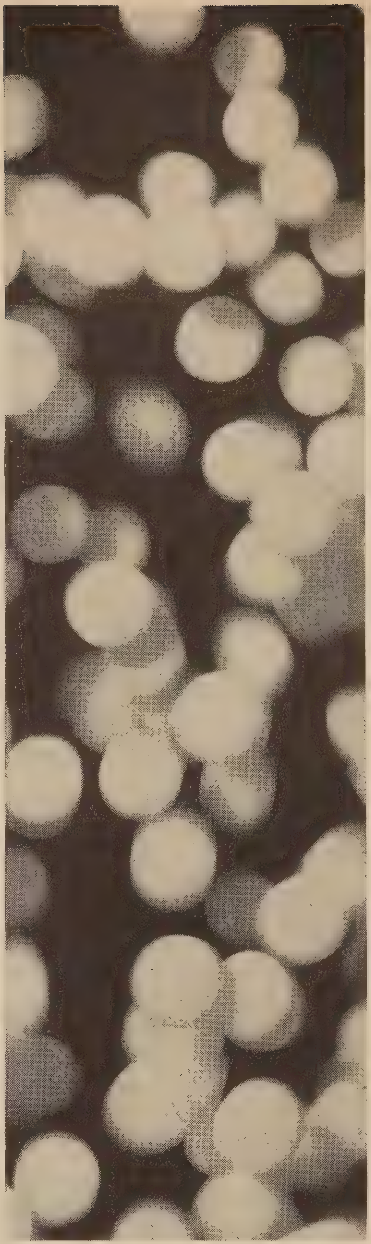

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(Continued from page 126A)

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Desires to relocate. Connecticut preferred. Excellent background in building and managing electronic sales organizations. Experienced in directing all phases of marketing activities. Age 37, married. Resume furnished on request. Box 2061 W.

UNIVERSITY ADMINISTRATOR

11 years college administration and teaching experience, plus industrial research, electronic design and development. Currently conducting year's research in industry. Have directed grant programs, technical adult education, research, taught undergraduate and graduate. BS. and MS. in E.E. Married. Age 36. Excellent references. Interested in challenging college position. Prefer Rocky Mountain area. Box 2062 W.

ELECTRICAL PATENT POSITION

BEE. Polytechnic Institute of Brooklyn 1958. Coast Guard officer desires position in Patent branch of organization located near a law school. Patent, law school and engineering experience. Box 2063 W.

ELECTRICAL ENGINEER

BSEE. 1957. 1/Lt. Sig. C. 1½ years as Project Officer at WSMR, New Mexico. Experience in the field of guidance and countermeasures of missiles. Interested in obtaining a LL.B. Desires position which requires an engineering and legal combination with management opportunities. Box 2072 W.

ELECTRONICS ENGINEER

European assignment desired in western or southern Europe in management, technical or liaison area. 15 years experience R and D, both civilian and military, in communications, electronic countermeasures, television and missile electronics. Considerable supervisory experience. BEE. and MEE. degrees. Box 2073 W.

ELECTRONICS ENGINEER

BS. in Physics. MSEE. 5 years experience in transistorized digital computer circuit design and radar-computer systems. Single, age 28. Desires position in western Europe. Box 2074 W.

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Communications systems engineering of telephone, radio relay, microwave, HF and SSB Systems. 20 years military experience all phases applied engineering, siting, installation, operation and maintenance. Performed Staff Engineering assignments at Pentagon and major command levels. Currently Deputy Chief, Maintenance Engineering & Test Branch, multi-billion dollar air defense project office. Supervisory experience with over 500 personnel. 21 months military electronics schooling plus BBA. and MBA. and 14 months training with industry. Senior Member IRE. Desires managerial position with growth potential. Available August 1960. Box 2075 W.

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Associate Professor of Nuclear Engineering desires summer employment leading to a con-

(Continued on page 130A)

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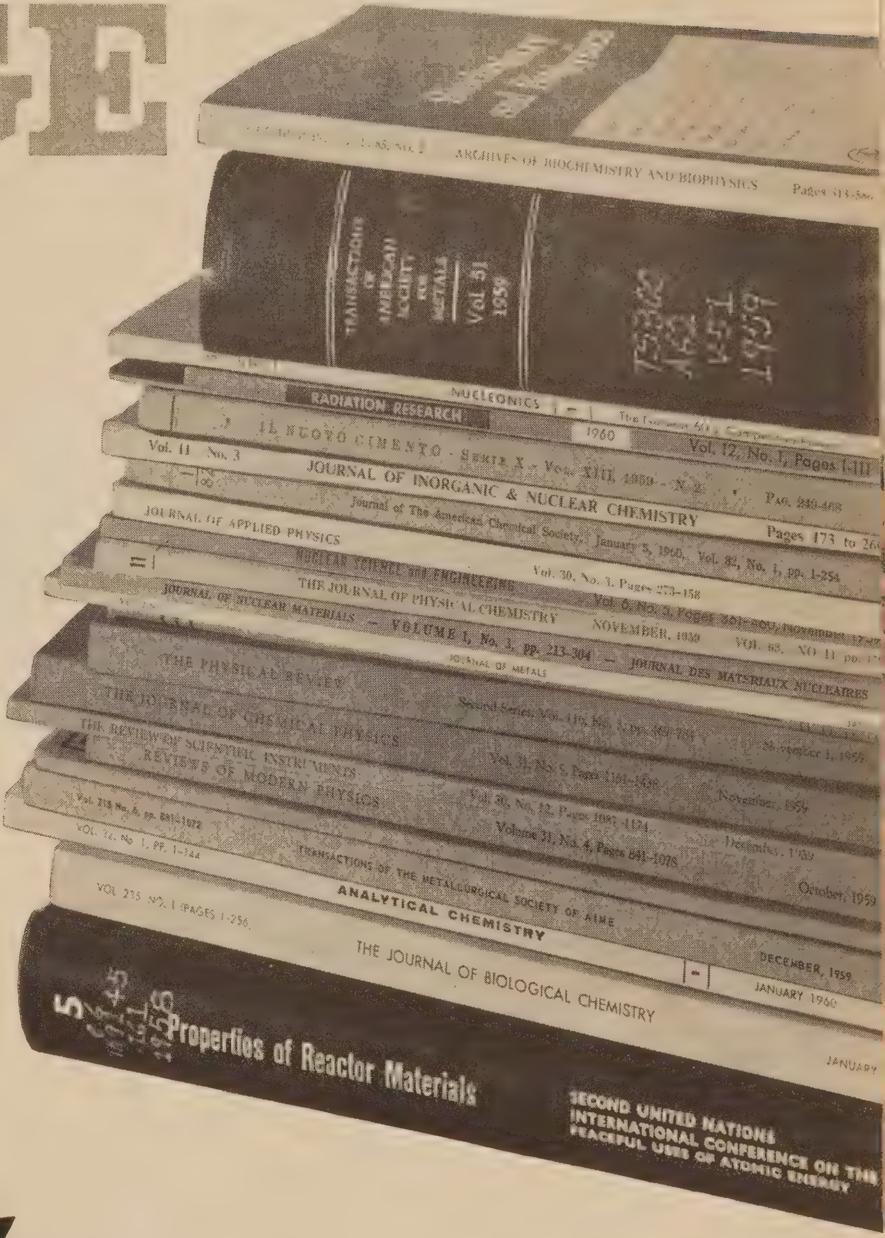
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Vol. 12, No. 1, Pages 1-111
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(Continued from page 128A)

sulting position; BSEE. 1949, MSEE. 1951; 7 years industrial and 3 years teaching experience in electronic and nucleonic instrumentation, microwaves and radioisotope techniques; active security clearance, AEC licenses, located in southwest. Box 2077 W.

ENGINEERING MANAGER

MSEE. degree. Background includes all levels in R and D to 3 years as manager of development groups. 12 years experience in analog and digital instrumentation, data processing, and automation with an even division between missile and industrial fields. Will relocate to either coast. Box 2078 W.

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Supervisory engineer of systems or sales on systems management or evaluation of electromechanical weapons system equipment in radar, computers, etc. and microwave components. Have excellent market and sales background with industrial and government agencies on prime hardware or components. Home base New York City or Long Island. Will travel extensively if necessary. MSEE. Matured. Formerly Lt. Colonel in the USAF. Box 2080 W.

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ENGINEER

Communications equipment, design circuitry and hardware. BSEE., MSEE. Seeks assignment Continental Europe. Top Drawer company only. Age 34; 9 years experience. Box 2082 W.

MEDICAL ELECTRONICS

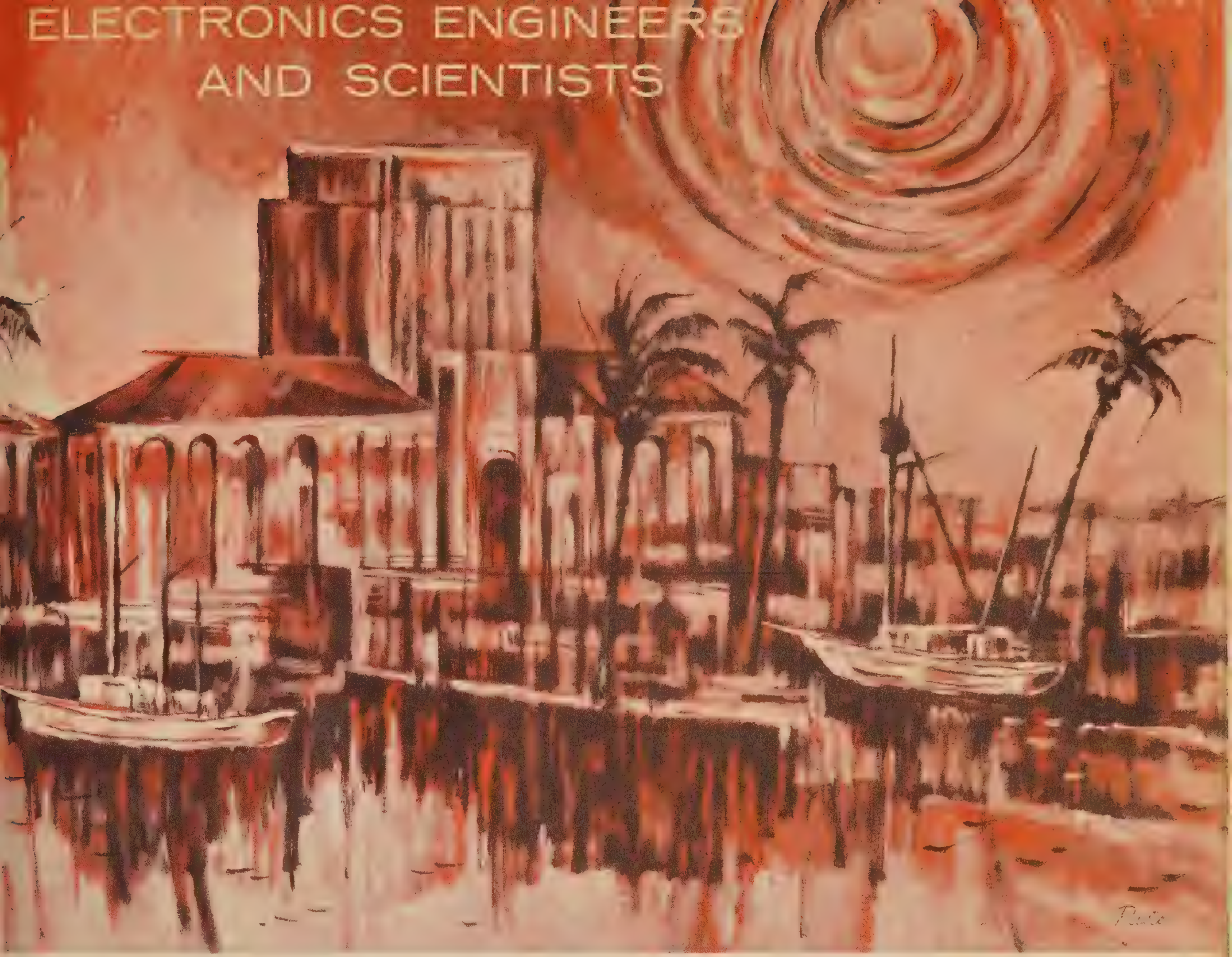
A.B. graduate courses in physiology and biophysics. Experience in clinical and research work with EEG, ECG, oximetry, pressures. Seeks position in maintenance with perhaps equipment operating and design duties. Box 2083 W.

ELECTRICAL ENGINEER

5 yr. E.E. plus good Liberal Arts background. Polyglot; age 31; family; lifelong U.S. citizen. Diverse experience ranging from power during military, 3½ years design and manufacture elec-

(Continued on page 133A)

ELECTRONICS ENGINEERS AND SCIENTISTS



San Diego Civic Center, an original painting by Sammy Pasto, Convair/San Diego artist

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THE ARTIST — Sammy Pasto, Convair-San Diego artist whose painting appears on the preceding page, is a native of Boston. He studied at the New England School of Art and moved to California following World War II. Presently working as an illustrator at Convair-San Diego, Pasto has received broad recognition for his work in fine arts. He has had one-man shows in New York, Philadelphia and Los Angeles and his work has been accepted in most juried West Coast art shows. For a change of pace, Pasto plays clarinet in a prominent Dixieland jazz band in San Diego.

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Secondary Specialty ______________________________

YEARS OF EXPERIENCE IN PRIMARY SPECIALTY: __________

Additional Comments, if any, concerning your job interests ______________

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By Armed Forces Veterans

(Continued from page 130A)

tric electronic instrumentation and control, 2 years solid state R and D, 1 year specifications and estimating for contracts and projects, 4½ years supervisory, presently project level problem solver and trouble shooter for large company on communication, navigation, ultrasonic and control. Box 2084 W.

ELECTRONICS ENGINEER

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Schneider, P. C., North Caldwell, N. J.
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Schwartz, S. S., Asbury Park, N..J.
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(Continued on page 134A)

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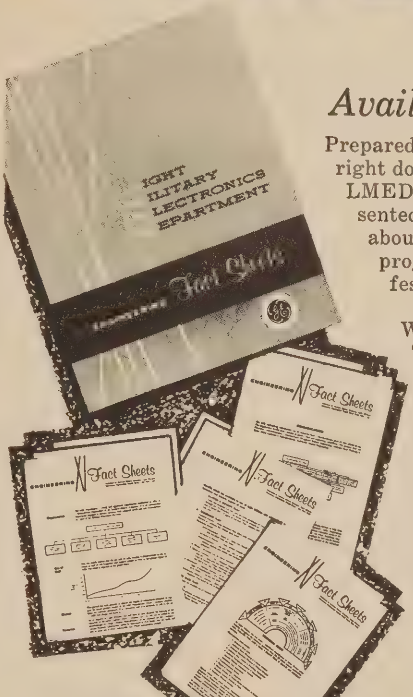

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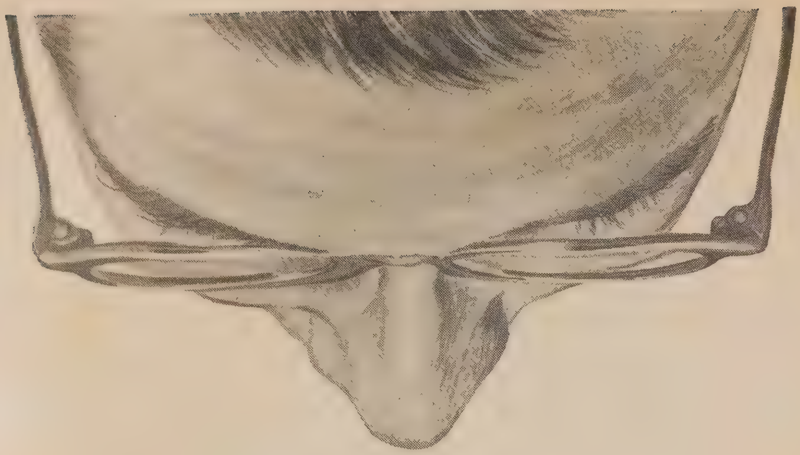

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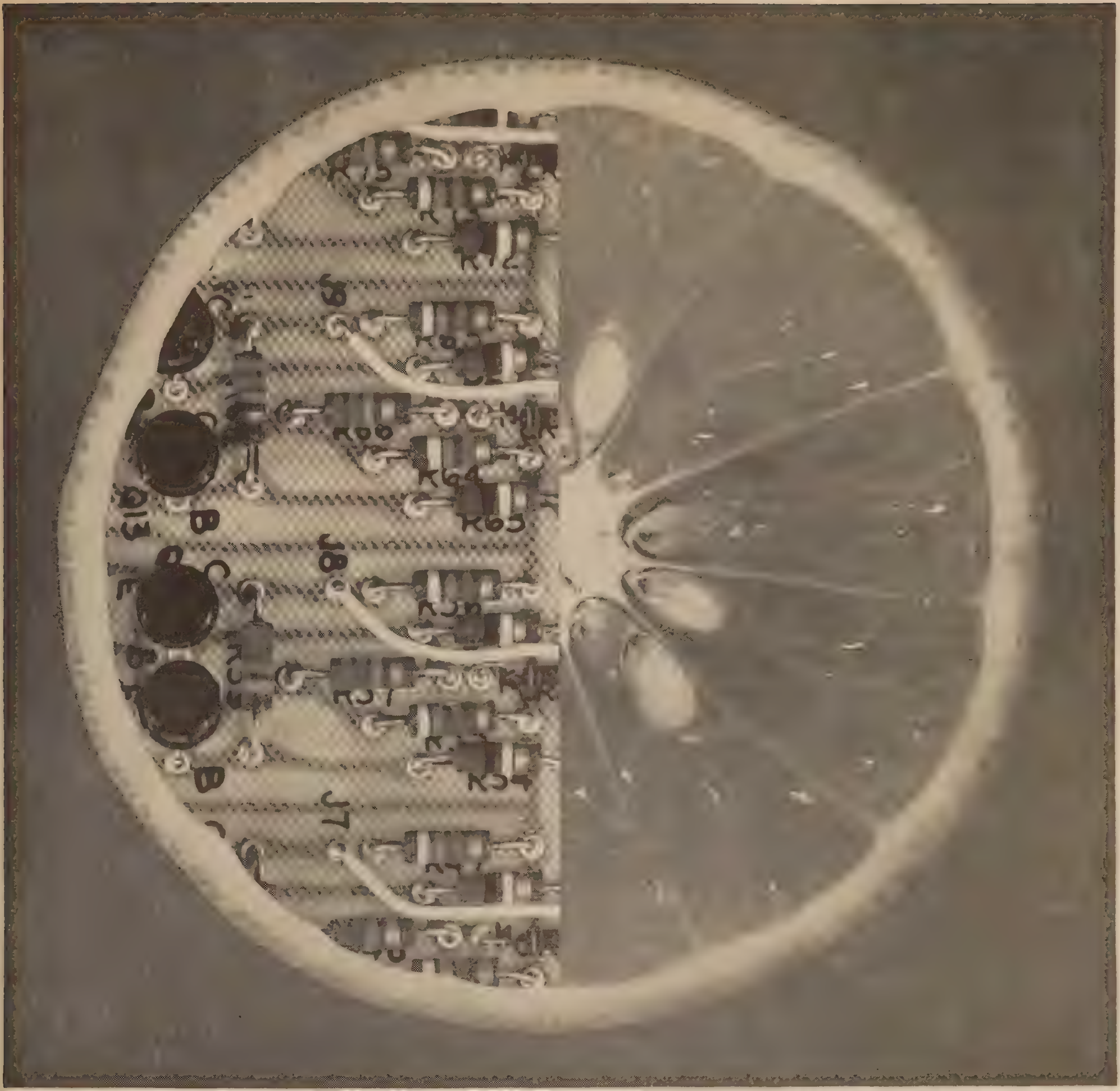
(*Continued on page 136A*)



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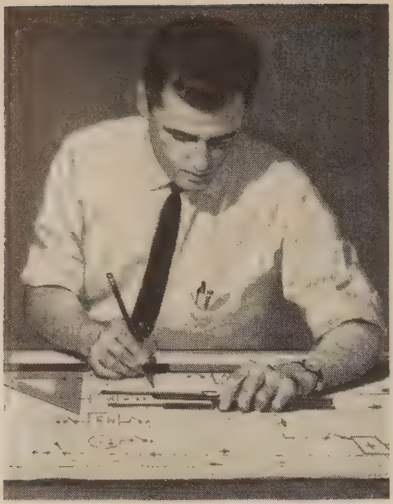

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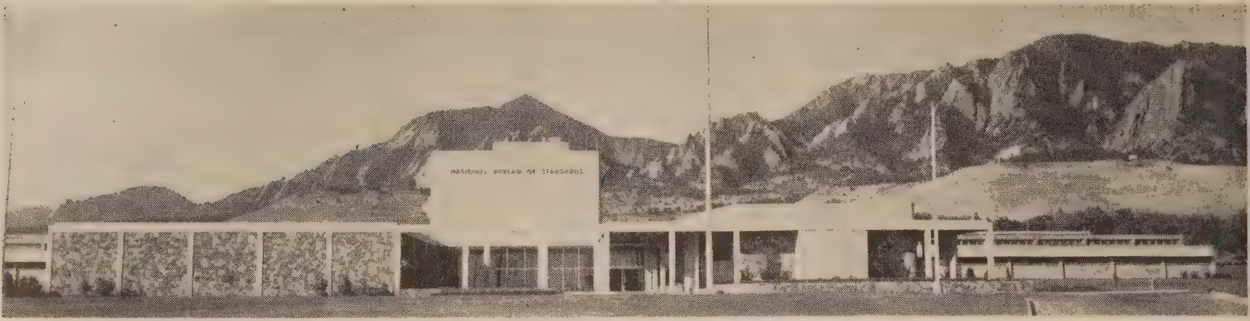

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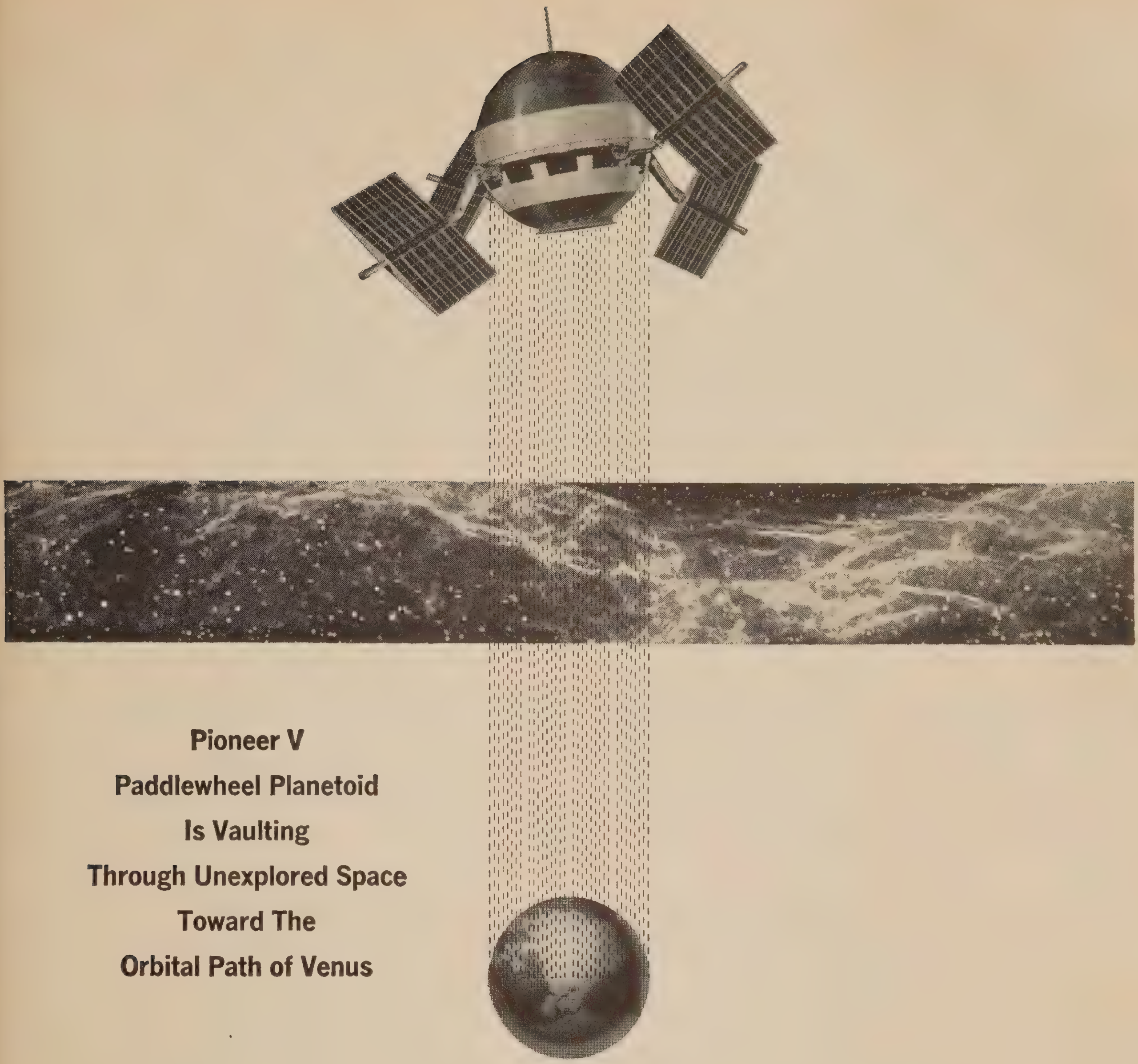

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BOMBING AND GUIDANCE SYSTEMS RESEARCH ENGINEERS to analyze and propose new systems and improvements for present systems of digital or analog bombing, navigational or search radar, doppler radar and associated flight test instrumentation; and to plan laboratory and flight tests and evaluate and analyze test results, using well-equipped electrical and computer engineering laboratories.

ELECTRICAL INSTRUMENTATION ENGINEERS to plan, design and develop instrumentation for new types of vehicles; monitor installation of test equipment, methods of recording such as electronic tracking components; and evaluate test data such as measurement of surface temperatures, heat transfer coefficients, pressure vibrations and acceleration strains as related to new product airframe design and testing.

COUNTERMEASURES SYSTEMS RESEARCH ENGINEERS to conduct research, analyze and develop improved techniques in the field of infra-red, ultra-violet and optics; including critical analysis of existing methods and knowledge required to advance the state-of-the-art applicable to defense and offense weapons.

PHYSICAL SCIENCES

ACOUSTICS AND ELECTRO-PHYSICS ENGINEERS to determine and predict sound levels to which aircraft structures, equipment and flight crew compartment are exposed; to develop noise suppression techniques, design test models; and experiment with transmission characteristics of new materials.

For immediate action on these or similar senior level openings which you are qualified to fill, contact Mr. Melvin Vobach, Boeing Airplane Company, Wichita 1, Kansas.

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Zenith Radio Corporation
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(Continued from page 142A)

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Tritschler, R. J., Poughkeepsie, N. Y.
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Turner, T. D., Chelmsford, Mass.
Tyler, L. A., Oak Park, Ill.
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Van Zant, F. N., Jr., Englewood, Colo.
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Wolff, J. P., Springfield, N. J.
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Bailey, E. H., Houston, Tex.
Barley, J. R., White Oak, Silver Spring, Md.
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(Continued on page 146A)

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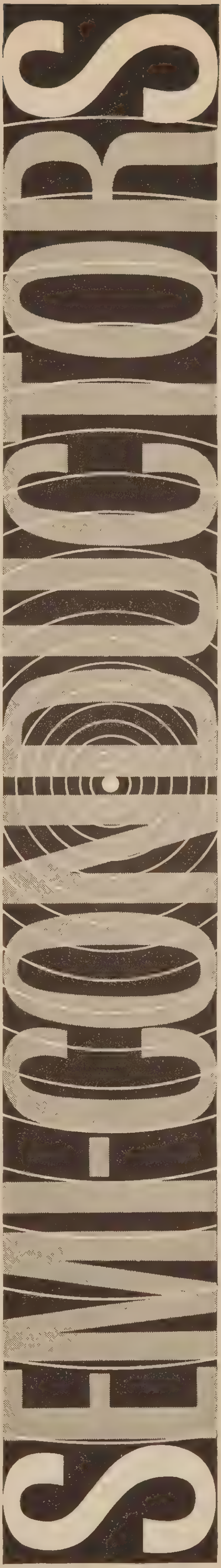

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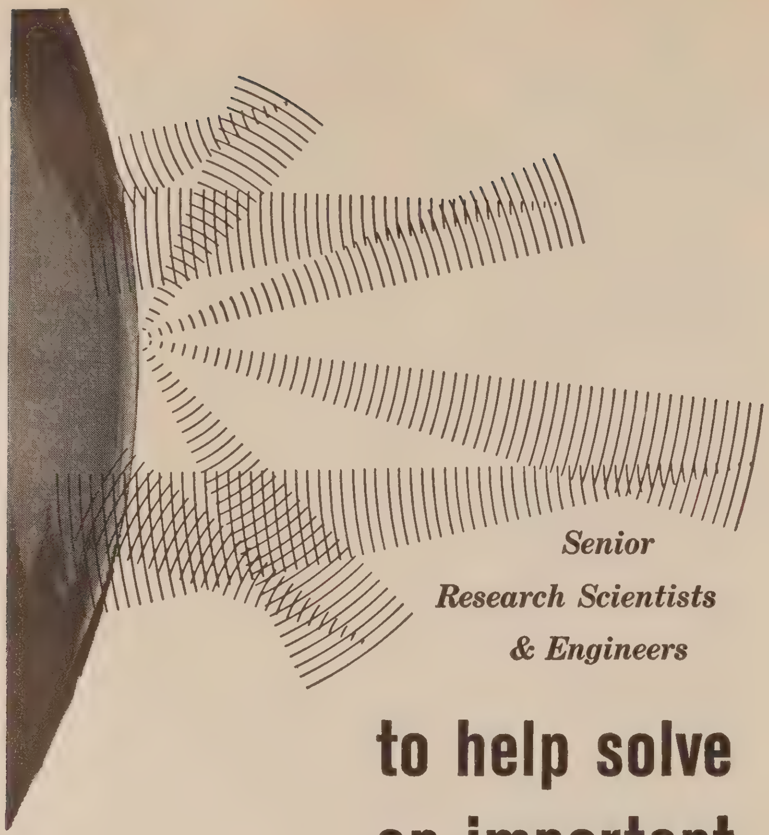

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(Continued from page 144A)

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If you are interested in, and qualified for one of these positions, send a complete resume to Technical Personnel Department.

New Positions are immediately available on both Commercial and Defense Projects:

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Advanced degree EE's and Physicists to handle conceptual studies in areas of solid state circuitry and semiconductors; molecular electronics; hydro-acoustics; digital data transmission; and speech analysis. Also openings for advanced degree mathematicians for study projects in information theory and related areas.

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Current openings at intermediate through technical supervisory levels for men experienced in communications systems; microwave circuit design; data handling and display equipment; air navigation control instrumentation; automatic test equipment and underseas warfare.

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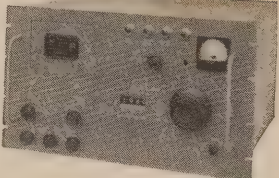

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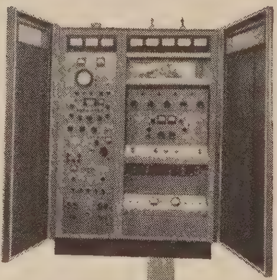
134A



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LITTON INDUSTRIES Electronic Equipments Division
Beverly Hills, California

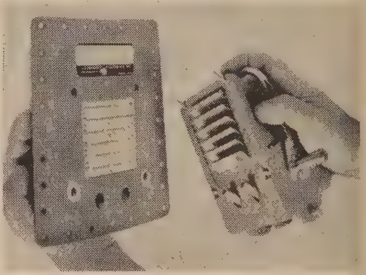
NEWS
New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 42A)

Umbilical Connector

Automation Electronics, Inc., an operating division of **Arnoux Corp.**, 11924 West Washington Blvd., Los Angeles 66, Calif., released data on its umbilical connectors which have been under development for some months. Already in use on an intermediate range missile, the unit is small, lightweight, and of integrated construction. The umbilical also features a mating and unmating mechanism so that the whole operation may be accomplished without the use of any tools.



This particular design provides for 300 individual contacts, each rated at 5 amperes and all are mounted in a space $2\frac{3}{4}$ inches square. The whole unit is sealed in a magnesium aluminum casing which matches a cutout in the missile skin. There are two fluid lines, each capable of carrying three gallons per minute with a maximum pressure drop of 6 psi. Disengagement is accomplished in two ways: normal motion of the missile disengages these contacts; and the plug may also be removed manually without missile motion.

The contacts are Multifilar and consist of heat-treated beryllium copper spring wires, which are silver-flashed and gold-plated. This design provides for high resistance to corrosion. Another advantage of this kind of contact is that a great number of disconnects are possible with very little degradation of the electrical contacts.

Further information may be obtained by writing to Arnoux.

Miniature Potentiometers

A new series of $\frac{5}{8}''$ diameter miniature compact composition variable resistors i offered by **Chicago Telephone Suppl Corp.**, Elkhart, Ind. Series 200 can be furnished with or without attached switch i standard bushing mounted construction o in the more economical ear mounting. Resistance range is 250 ohms through 2. megohms linear taper, wattage rating watt through 100,000 ohms and 2/10 wat over 100,000 ohms at 55°C derated to n load at 85°C, voltage rating 750 vac bushing to terminals for 1 minute high pot tes and 500 vdc operating maximum, 35 vdc across end terminals and 280° rotatio without switch, 315° with switch. De

(Continued on page 150A)

General Motors pledges
AC QUESTMANSHIP
2

AC Seeks and Solves the Significant—Inspired by GM's pledge to contribute heavily to our national defense, AC, an acknowledged leader in the new technology, plans to reach far beyond such accomplishments as AChiever inertial guidance systems. / This is AC QUESTMANSHIP. It's an exciting scientific quest for new ideas, components and systems . . . to promote AC's challenging projects in guidance, navigation, control and detection. / Mr. Jack Briner, AC Director of Field Service, believes his department's Career Development Program "offers young engineers world-wide opportunities in the practice of Questmanship." They learn a product from its technological theory through its operational deployment. Following this training, "they utilize their own ingenuity to support AC products in the field, with more effective technical liaison through training, publications, maintenance engineering, and logistics." / You may qualify for this special training, if you have a B.S. in the electronics, scientific, electrical or mechanical fields. Special opportunities also exist at AC for men with M.S. and Ph.D. degrees. If you are a "seeker and solver," write the Director of Scientific and Professional Employment, Mr. Robert Allen, Oak Creek Plant, Box 746, South Milwaukee, Wisconsin.

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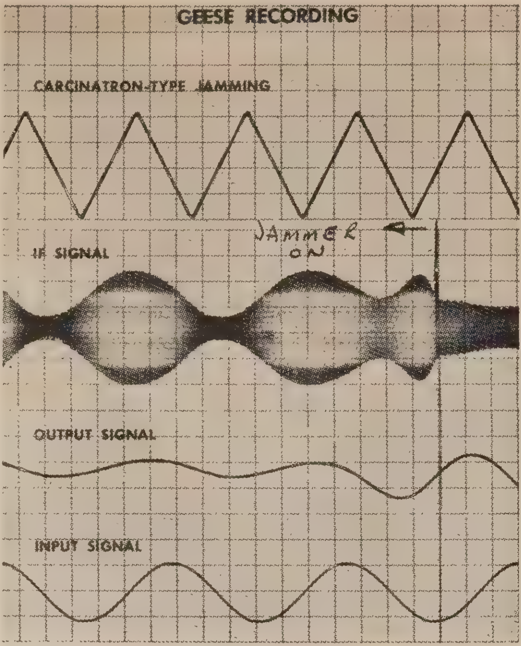


EVOLVING LARGE-SCALE SYSTEMS CONCEPTS

AND DEVELOPING THE TOOLS THAT SPEED THEIR DESIGN CYCLE

Defense Systems Department is directing its technical capabilities toward the development of large-scale electronic systems. Inherent within this work program is the recognition, definition and solution of problems in every aspect of the systems technology.

To accomplish this ambitious task, a growing number of studies are being directed toward the development of unique tools that will aid in the design of superior systems in less time, at lower cost.

A recent contribution by Defense Systems Department in this technological area is GEESE (General Electric's Electronic System Evaluator). Utilizing advance computer techniques, it enables systems engineers to accurately predict, optimize and synthesize system performance prior to design.

GEESE is indicative of the scope of Defense Systems Department's involvement in the systems technology. Many programs offer systems-oriented engineers and scientists an opportunity to participate in new areas of long-term importance.

Senior members of our technical staff would welcome the occasion to discuss personally and in detail the career positions available with this growing organization. Address your inquiries in professional confidence to Mr. E. A. Smith, Box 4-F.

DSD DEFENSE SYSTEMS DEPARTMENT
A Department of the Defense Electronics Division

GENERAL ELECTRIC

Northern Lights Office Building, Syracuse, New York

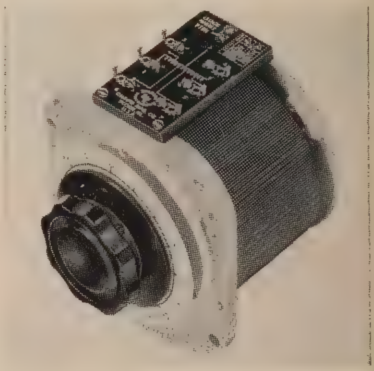
These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 148A)

signed for commercial applications where space is at a premium. For applications requiring extremely compact control and SPST switch combinations, unique Type QS-200 combined switch and control in a single miniature molded housing. Base prices in 3000-9999 quantities for the various Series 200 constructions start at $160.42 M without switch and $316.93 M with switch. Delivery 4 to 5 weeks after sample approval.

Variable Transformers

Individual transformers operating from a single-phase, 240-volt line are now available from **Ohmite Manufacturing Co.,** 3696 Howard St., Skokie, Ill. Model VT8H is rated 3 amperes and at maximum setting will deliver line voltage (240v) or overvoltage (280v). Model VT8HN is the "no-overvoltage" type which will deliver just line voltage at maximum setting, but offers a current bonus in its output rating of 4 amperes.



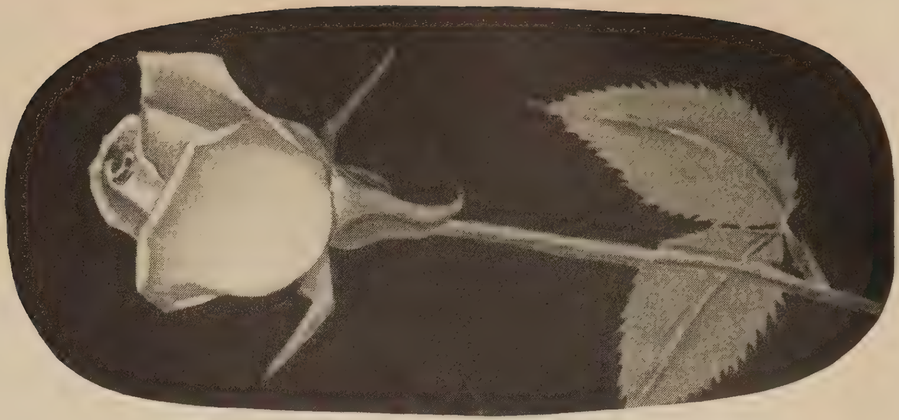
Both models are constructed on the same frame as Ohmite's popular VT8 series (ratings for 120-volt input types; 7.5 amperes with overvoltage; 10.0 amperes without overvoltage). The "high voltage" units afford the convenience of 240-volt, single-phase operation using a single unit instead of a ganged assembly. The 240-volt, single-phase operation can also be achieved with ganged assemblies of 120-volt input transformers where higher power output is desired.

The transformers have a tap which permits operation at 120 volts input with 280 volts output for the VT8H and 240 volts output for the VT8HN (some derating is required for output beyond 120 volts). These high voltage transformers can also be obtained in ganged assemblies to achieve 240-volt, 3-phase operation or 480-volt single phase or 3-phase operation. Request Bulletin 151.

Sweep Generator

A new Sweep Generator is now available from **Telonic Industries, Inc.,** Beech Grove, Ind., with twice the sweep width of

(Continued on page 152A)



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There are many worthwhile advantages awaiting the Professional Engineer who chooses to advance his career with us at Bendix York.

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The white rose is a symbol at Bendix York . . . a symbol with two meanings. Both of vital importance to *your* future.

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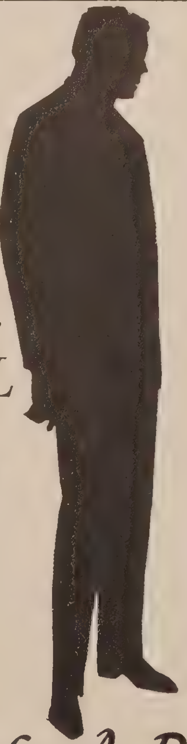

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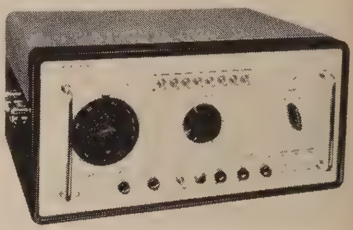
NEWS New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 150A)

earlier models having the same range and power output. The new Model HD-1A, has a center-frequency range of 1 to 900 mc, and a sweep width that is adjustable up to 200 mc in the lower portion of the range.



The wide range is achieved by using two UHF swept oscillators, each with a range of approximately 400 to 900 mc. These are combined in a heterodyne circuit to produce a third signal that is tunable over a 1-to-400 mc range. The output of a single oscillator is used for the instrument's upper range, providing a continuous spectrum of center frequencies from 1 to 900 mc.

Sweep widths may be varied from 200 mc in the heterodyne portion of the center-frequency range. Over 400 mc, the sweep width is variable from 0.06 to 10% of the center frequency. Attenuators, detectors and other circuit elements are carefully designed for broadband performance so that the output is level across the entire swept frequency, even when set at the widest limit. The two oscillators are leveled by an automatic-gain-control circuit that continuously samples the swept output. Specifications for the HD-1A call for a flatness of less than ±5% at maximum sweep width.

The RF output of the instrument is a maximum of 0.75 volts, peak-to-peak, across the heterodyne range and 2.0 volts, peak-to-peak, in the high range. These voltages are adjustable by a turret attenuator mounted on the front panel of the instrument. Settings are provided for 0, 10, 20, 30, 40, and 50 db attenuations, plus a 0–10 db vernier.

By automatically blanking the return sweep, the Model HD-1A instrument provides a base line on the scope presentation. The horizontal sweep signal is 20 volts, peak-to-peak, with a repetition rate equal to line frequency, 50 to 60 cps.

Toggle switches on the face of the instrument introduce fixed "birdy" markers into the oscilloscope trace. Up to eight plug-in marker units may be used, each set at the factory to a particular frequency. In addition, harmonic plug-in markers are available that add birdies at 1 mc, 10 mc or other intervals.

High Temperature Precision Capacitors

A new line of precision film capacitors is now available in the −55°C to 125°C

(Continued on page 155A)

ASTRONAUTS IN SEARCH OF A HELMSMAN

(it could be you!)

ELECTRONICS ENGINEERS: IT'S TIME TO SET YOUR COURSE WITH THE WORLD LEADER IN CONTINUOUS WAVE DOPPLER NAVIGATION SYSTEMS

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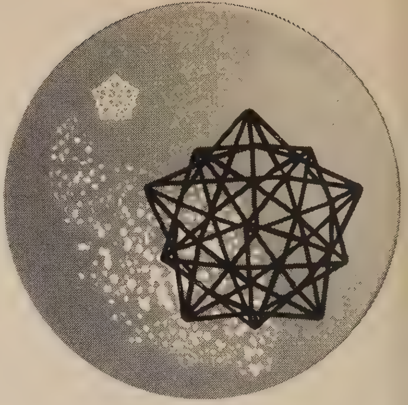

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Expanding the scope and depth of present programs is Republic's recently completed $14 million Research and Development Center. Extensive facilities here are an invitation to professional men to realize the future by solving today's most perplexing problems.

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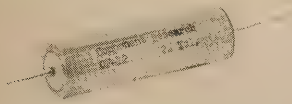
(Continued from page 152A)

temperature range from **Component Research Co., Inc.,** 3019 So. Orange Drive, Los Angeles 16, Calif.



The capacitance change is less than 1% for the entire range. From 25 to 125°C the capacitance change is less than ±0.3% and zero ±30 ppm /°C temperature coefficient, which remains stable with repeated temperature cycling.

Insulation resistance is greater than 10^{13} ohms. Dielectric absorption is less than 0.0003 when measured with a charging voltage of 44 volts for 30 seconds.

The dissipation factor remains less than 0.0003 over the entire temperature range and a wide range of frequencies.

These CR PROCESS (pat. pend.) capacitors have a standard tolerance of 2% and are hermetically sealed in tubular and bathtub enclosures. Other tolerances ranging to 0.1% are available at all standard working voltages.

Special capacitors with less than ±0.3% total capacitance change from −80°C to 125°C can be supplied for unusually critical circuit applications.

These precision capacitors can be used in computers, timing circuits, servo systems, pulse filter networks and a variety of other applications.

Fire Retardant Casting Resin

Emerson & Cuming, Inc., Canton, Mass., announces a new fire retardant epoxy casting resin which may be cured at room temperature. The material has excellent adhesion to metals, plastics and ceramics.

Due to its low thermal coefficient of expansion and high heat stability, large embedments can be made. It is stable over a temperature range of −100 to +350° F. Stycast 1231 can be color coded to specification but normally is supplied in black.

(Continued on page 156A)

MAN OUT...

A fascinating project at Martin-Denver and one which offers to the truly creative engineer or scientist a personal esteem and professional recognition unequalled in today's opportunities. Please do consider being a part of this or other creative involvements at Martin-Denver and inquire of N. M. Pagan, Director of Technical and Scientific Staffing, (Dept. DD 9), The Martin Company, P. O. Box 179, Denver 1, Colorado.

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The Brown Instrument Division of Honeywell has several openings for development engineers. Work involves responsibility for projects from drawing of the original requirement specifications, through the development and design phases, until finished drawings and specifications are released to the manufacturing department.

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Engineering grads with at least 1 year in electronics development work. Present or contemplated projects include development of high gain, low level d-c servo amplifiers; computing elements for industrial process control loops utilizing transistor and magnetic amplifier circuitry; sophisticated controllers for process control utilizing diode modulator techniques with a high audio frequency carrier; and high gain, wide band d-c amplifier development.

JR. & SR. ELECTRICAL ENGINEERS

BSEE's with at least 1 year of experience in the development of electrical measuring instruments such as potentiometer recorders with microvolt sensitivity, galvanometer indicating controllers, current actuated recorders, etc. Also involves development of many types of electrical transmitters and components such as strain gauges, galvanometers, slidewires, torque motors, and electro-mechanical transducers. Frequently the work on these instruments involves telemetering components, integrators, controllers and alarm devices.

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Wayne and Windrim Avenues, Philadelphia 4, Pa.

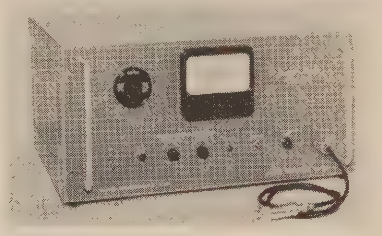
To explore professional opportunities in other Honeywell operations coast to coast, send your application in confidence to B. I. Eckstrom, Honeywell, Minneapolis 8, Minnesota.

(Continued from page 155A)

Thin sections of cured Stycast 1231 repeatedly introduced to a flame will, on each occasion, immediately extinguish.

Noise Source

The Mega-Node 3000, a noise-diode type calibrated noise source, providing low VSWR across a frequency range of 1 to 3000 mc, has been introduced by the **Kay Electric Co.**, Dept. PI, Maple Ave., Pine Brook, N. J., manufacturers of precision electronic test and measuring instruments.



Accurate noise-figure measurements require diode current to be known and generator impedance to be constant with frequency, since available noise power is a function of both. In the Mega-Node 3000, the generator impedance is held constant across the range by an impedance matching device that is simple in principle. Thus, the error introduced by the generator

(Continued on page 158A)

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(Continued from page 156A)

VSWR (impedance variation) is minimized.

Rapid, accurate measurement of noise-figure can be accomplished without calculation of the effective bandwidth. Variable noise-power range and low VSWR permits accurate noise-figure measurements. Calibration charts and slide rule are not required to determine noise-figure.

A coaxial-type, tungsten-filament noise diode is employed as a temperature-limited noise-generator. Plate voltage is regulated and diode plate current, which is proportional to noise power output, is adjustable by a front panel control. Current is indicated on the panel meter, calibrated in noise-figure. To prolong the life of the noise diode, an automatic cutoff is incorporated to limit the time of operation at high currents.

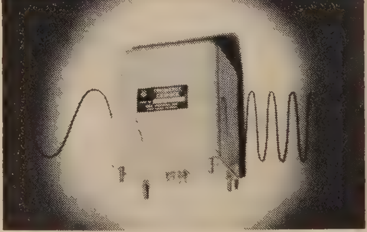
The panel meter reads noise-figure directly up to 20 db for a 3 db Y-factor. Maximum VSWR is 1.15 from 1 to 250 mc; 1.25 from 250 to 2000 mc; 1.4 from 2000 to 3000 mc. Noise-figure accuracy is ±0.25 db from 1 to 250 mc. At the higher frequencies, the noise-figure error (db) is a function of the generator VSWR, but does not exceed SWR (db)/2.

Maximum VSWR indicated occurs at frequencies which represent less than 20% of the total frequency range. The VSWR over most of this range is much lower than the maximums specified.

Specifications: Frequency Range, 1 mc to 3000 mc; Output Impedance is Nominal 50 ohms (type-N connector); Noise Figure Range, is 0 to 20 db; Meter Calibration, Logarithmic in db noise-figure and linear in dc ma; Noise Diode, Bendix Type TT-1. Power Supply, Input approximately 200 watts, 117-v (±10%), 60-cps (Available for 50-cps operation on special order). B^+ electronically regulated. Dimensions, $9\frac{3}{4}'' \times 19\frac{1}{2}'' \times 15\frac{1}{2}''$; Weight: 44 lbs.

Transistorized Frequency Changers

ERA Pacific, Inc., 1760 Stanford St., Santa Monica, Calif., announces new additions to its line of transistorized frequency changers. These units convert one input frequency to a second frequency at power levels and eliminate the disadvantages inherent in vacuum tube or mechanical equivalents. The new units are designed for powering all types of AC equipment, gyro and servomechanisms, magnetic amplifiers and are intended for laboratory and industrial applications.



(Continued on page 163A)

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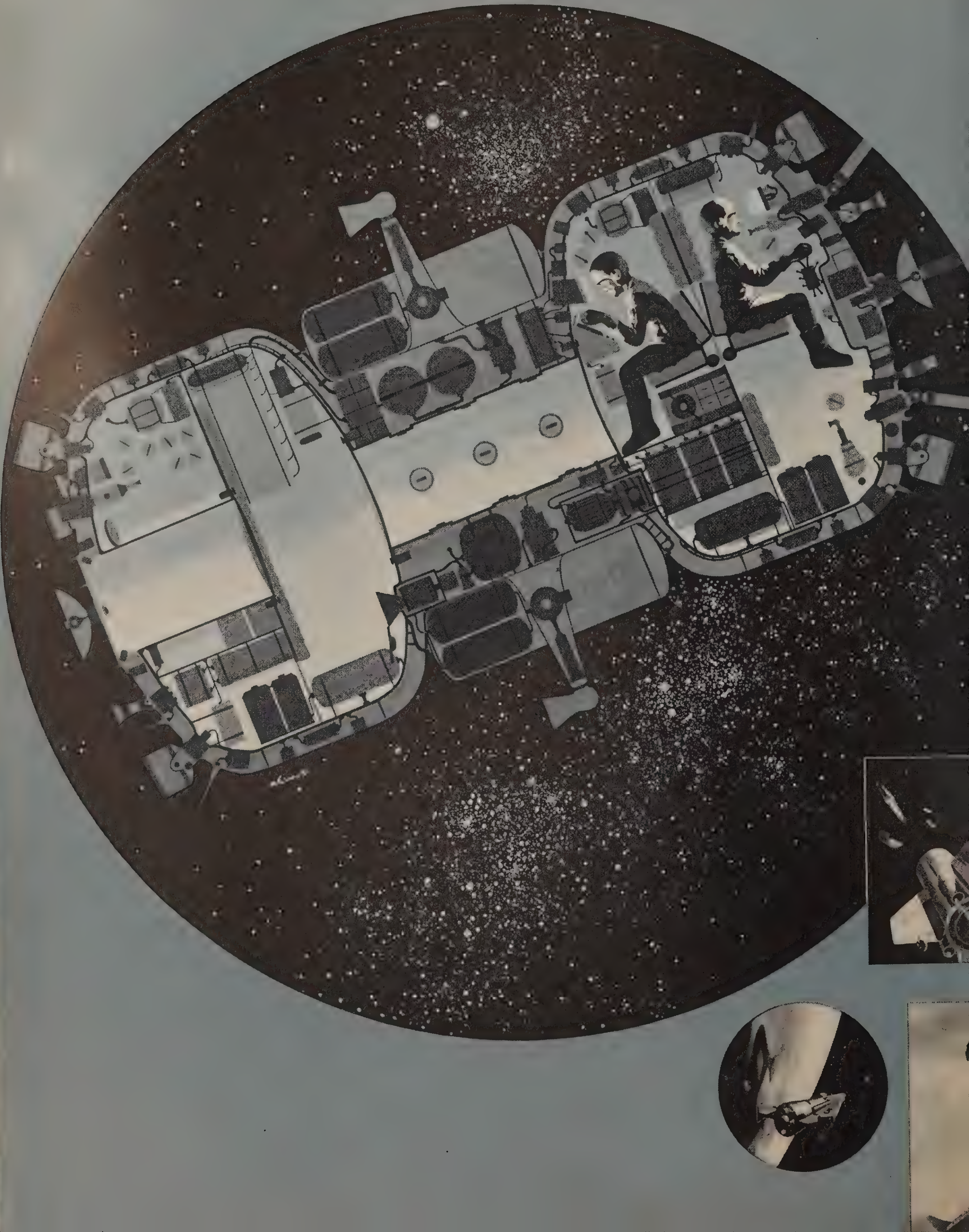

THE
STROTUG

Tugboat for Space: Spaceborne scientific laboratories and platforms for further exploration into space are an accepted concept based on established engineering techniques. Components would be fired as individual units into space, on precalculated orbits, and there assembled. To solve the major problems of how men are to live and work in space during the assembly process, Lockheed has prepared a detailed engineering design of an astrotug - a manned vehicle housing a crew of two or three. Missile-launched, the astrotug will be capable of supporting its crew for a number of days in an environment of suitable atmosphere, artificial gravity, and with provisions for exercise, relaxation, bathing facilities, medical care, illumination and adequate food and water.

The Lockheed astrotug is a completely independent working vehicle. Personnel need not leave it in space suits in order to work on the project of assembling the space station components. As shown in the diagram, the tug consists of two double-walled pressure vessels approximately 20 feet long overall and 9 feet in inside diameter. Swivelling rocket nozzles are arranged for maneuvering. On the forward end, extending out are four mechanical manipulator arms with interchangeable "hands" for such specialized functions as gripping, welding, hammering, cutting, running screws, etc. "Hands" can be changed by remote control from inside. Viewing ports provide uninterrupted observation. Radar antennas, searchlights, and other equipment necessary to the tug's work are mounted externally. Main controls and instruments including radar, radio, infrared, computers and navigation consoles are duplicated in each of the two major compartments as a safety measure.

Men working in single units afloat in space suits would have little applicable force and could work for very limited periods of time. With the Lockheed astrotug, personnel could carry on the work in relative safety and comfort with maximum efficiency. A special reentry vehicle, separate from the astrotug, has been conceived for ferrying to and from earth. Tugs themselves would remain floating in orbit indefinitely, being reprovisioned and refurbished as fresh crews arrive in relief.

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LEADERS IN NEW PROJECTS AND ADVANCED STUDIES

Applications are invited from scientists for positions in which they will lead groups conducting feasibility studies in Advanced Weapons Systems and Satellite Projects.

Candidates should preferably have had experience of Research or Development work in related fields, but previous work on Guided Weapons, Aeronautics or Armaments is in no way essential. Degree or equivalent qualifications in either Physics, Mathematics, Electrical or Aeronautical Engineering is necessary.

For these posts (equivalent approximately to Principal Scientific Officer) the Company will give assistance with housing and removal expenses.

Please write to Dr. D. A. Layne, c/o Dept. C.P.S. Marconi House, 336/7, Strand, London, W.C.2, England, quoting reference 1395D.

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 158A)

Three new models are available—the Model FC 6415 which converts an input frequency of 60 to 400 cps at a 150va power rating, the Model FC 6410 which converts a 60-cycle input to a 400-cycle output at 100 va, and the Model FC 645 at 50va. These models provide a regulated output frequency compensated against both input and load variations.

The new models achieve frequency conversion by means of special circuitry which converts the input frequency to dc by means of silicon rectifiers. This dc, in turn, is converted to the desired output frequency by means of stabilized transistor keyers. This design approach permits desirable achievements, such as instant starting, small size, light weight, zero maintenance, negligible radio interference and high shock vibration resistance characteristics.

Contact-Making Wattmeter

A new kind of ac-dc contact-making wattmeter, capable of both indicating and controlling power in the lower milliwatt range, is announced by **Assembly Products Inc.**, Chesterland, Ohio.

(Continued on page 165A)

gp

Now that you're back . . .

. . . after attending the IRE Convention in New York, give serious thought as to where you're going.

If the position you're holding is just a job, without creative satisfaction, take the big step. Jot down a resume; send it to GUILFORD. All FEES PAID.

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for

research programs

in

IONOSPHERIC PROPAGATION
& HF COMMUNICATIONS

senior ionospheric physicists

Ph.D. preferred, with several years' experience in Ionospheric Phenomena studies. Familiar with latest knowledge of upper atmosphere physics and of programs using missiles and satellites for Ionospheric studies. Persons with supervisory capabilities will have the opportunity to assume leadership of HF projects already underway in the first phases of a substantial experimental program.

senior development engineers

Senior Scientists and Senior Engineers with current experience in state-of-the-art techniques in the design and development of HF receivers and transmitters. Specific experience desired on High-powered HF linear circuits. Work is evenly divided between engineering and development, including breadboarding.

senior electronics engineers

R & D Operations Liaison. Must have demonstrated technical ability to direct the incorporation of modern ideas into field equipment: to actively participate in the equipment transition from prototype to operational status. These are senior appointments as liaison between our R & D Equipment Development Laboratory and Field Operations. Degree in E.E. and the ability to communicate effectively are required.

junior electronics engineers

To assist Senior Engineers and Scientists in the development of HF communications and Data Process equipment. Should have formal electronics schooling and two years' experience in circuit design, checkout or analysis of HF Communications, Radar Pulse, Analog/Digital or Data Recovery equipment. Construction of prototypes of new and interesting equipment of these and design of individual components of communications and data processing systems will comprise the major efforts of selected applicants.

The Electro-Physics Laboratories are located in the suburban Washington, D.C. area, where post-graduate study is available in several nearby universities. Housing is plentiful in attractive, well-established neighborhoods. Our relocation allowance is liberal. Inquiries are held in complete confidence. A prompt reply will follow the receipt of your resume by:

Mr. Robert J. Reid
Technical Employment Manager

ACF ELECTRONICS DIVISION

acf

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RIVERDALE, MARYLAND WARFIELD 7-4444

po-si′tion

Problem: Determine positional accuracy of automatic inertial navigation system.

Solution: Celestial check by Nortronics' visual Type 11 Periscope System or submarine Radiometric Sextant, Mark II.

Result: Bird away and on target.

Pioneering by Nortronics' Precision Products Department in the field of navigation and stabilization systems has created unique career opportunities in advanced design, production and applications engineering.

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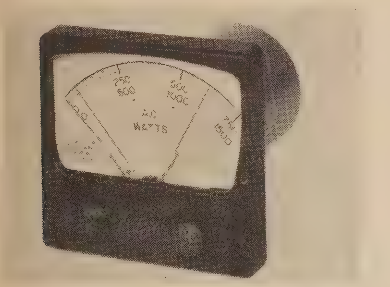
These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 163A)

Although primarily intended for measuring power, the unit also is available in modified form as a true RMS voltmeter or ammeter, or as a varimeter. The instrument can monitor the product of as many as four different variables.

Main elements of the instrument are a locking contact meter-relay and a magnetic circuit built around a Hall effect solid state device. They come in a panel-mounting package with a 4½-inch meter and a barrel less than 5 inches long.



Greatest standard full scale sensitivity at present is 500 milliwatts, either ac or dc, but with modifications dc ranges as sensitive as 100 milliwatts are available. The instrument can be built to operate on any ac frequency up to 1000 cps. Either ac or dc must be specified—they cannot be measured interchangeably by a single instrument.

Power measurement is simplified by eliminating the standard dynamometer movement of wattmeters. This is possible because the Hall device puts out a voltage that is proportional to the power in a load circuit. The output voltage is fed to a standard D'Arsonval movement that is directly calibrated for power measurement.

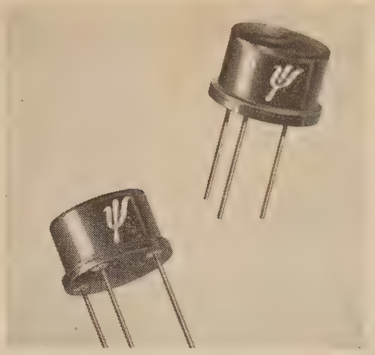
As with standard API locking coil meter-relays, control action begins whenever the signal pointer reaches a limit set by either a high or low adjustable pointer. Circuits are then closed that actuate load relays and other control components.

The new wattmeter is available with any of the standard API circuits used with locking contact meter-relays to provide a variety of control patterns. One of the more obvious applications is controlling motor load, since power is a more reliable measurement factor than the current alone that is frequently used.

Where remote indication or control adjustment is desired, the meter-relay and the associated circuitry are furnished in two packages for separate mounting.

Silicon Mesa Power Transistor

Pacific Semiconductors, Inc., 10451 W. Jefferson Blvd., Culver City, Calif., announces very high frequency silicon mesa power transistors capable of delivering one watt power output at 70 mc with a 28 volt collector voltage.



The two new types, designated as 2N1505 and 2N1506, are characterized by 3 watt collector dissipation, 40 volt collector to emitter rating, and low collector capacitance. The units are suited for VHF power application in communications and telemetry equipment where severe environmental conditions are encountered.

Type 2N1505 operates as an oscillator at 70 mc with a power output in excess of 1 watt at an efficiency of 45%.

Type 2N1506 has a typical power gain of 12 db at 70 mc with a useful power output of 1.0 watts. At 200 mc the 2N1506 has a power output of 300 milliwatts.

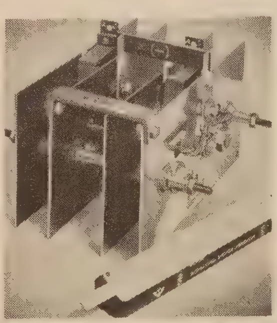
Delivery is currently being made on both new types. The 2N1505 is priced at $39.50 up to 99 pieces at $29.60 up to 1000 pieces. The 2N1506 is $49.50 and $37.00 respectively.

The new types supplement the present PSI line consisting of high frequency, high power, high voltage types 2N1335–1341, the multipurpose high speed switches 2N1409–1410 and medium power high speed types 2N696/697.

Detailed technical data on the 2N1505 and 2N1506 transistors is available from the factory.

High Power Silicon Rectifier Stack

Pre-engineered high power silicon rectifier stacks incorporating built-in paralleling reactors to insure equal current distribution through parallel circuit branches are now available from **International Rectifier Corp.,** 1521 E. Grand Ave., El Segundo, Calif. The units feature ratings up to 750 amperes, with from 50 to 600 volts peak reverse voltage ratings.



A standard "building block" is a 2-1-2-D "doubler" module with integral parallel-

(Continued on page 167A)

po-si′tion

A NOTE FOR TALENTED ENGINEERS:
We invite your inquiry as to important positions that exist at Nortronics' Precision Products Department (formerly the Military Products Division of American-Standard).

Plan your future with Nortronics' Norwood team and stimulate your professional growth. If you can qualify in one of several electro-mechanical areas you will work on challenging programs with professionally dedicated associates.

FOOTNOTE: *Excellent salaries for qualified engineers in both our Systems and Components Groups.*

Contact E. P. REARDON,
NORTRONICS Precision Products Department,
Norwood, Massachusetts

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Right now, things are really humming at the Link Division of General Precision, Inc. Link is one company which has accepted the challenge of the years ahead with eager enthusiasm. In fact, projects now under way at Link are among the most advanced in the nation.

At Link, engineers are busily engaged with research and development on "Dialog" systems, sub-systems and components. Another example of Link/ability, "Dialog" systems planning combines digital computation with analog measuring. It offers the best of both—in compatible form—to meet the most exacting control, design, analysis and scheduling specifications.

But let's be honest. Without top caliber engineers we can't really do anything. That's why engineers coming to Link today have Opportunity with a capital "O".

If you are an electronics engineer who thinks big—who has original ideas and follow-through to make them click, why not write today, or send your résumé—in complete confidence—to:

Mr. C. P. Darrah
Link Division
General Precision, Inc.
Binghamton, New York

Mr. R. P. Rutman
Link Division
General Precision, Inc.
Palo Alto, California

LINK DIVISION **GENERAL PRECISION, INC.**

BINGHAMTON, NEW YORK
PALO ALTO, CALIFORNIA • COLLEGE PARK, MARYLAND

(Continued from page 165A)

ing reactor, and four 70 ampere rated silicon junction rectifiers mounted on copper cooling fins. Two of these modules may be mounted to from a single phase bridge (as shown in photo) rated up to 550 amperes rectified dc output (when operating within recommended temperature and cooling limits).

Three of these basic modules will form a 3-phase bridge rated to 750 amperes. Other configurations include "Scott 4-phase bridges," and 6-phase bridges in both series and parallel connections and proportional ratings.

For detailed data on this new high power silicon stack line, request Bulletin SR-336.

Piore and Palmer Appointed By IBM

A separation of the corporate staff research and engineering function of **International Business Machines Corporation** into two functions was announced today by President Thomas J. Watson, Jr.

Dr. Emanuel R. Piore, IBM director of research, will now report directly to A. L Williams, IBM executive vice president. Dr. Piore was also named chairman of the company's Research and Development Board. The board serves to assure the most effective direction and·use of IBM's total technical resources.

Ralph L. Palmer, IBM director of engineering, will also now report to Williams and will continue to exercise staff supervision of the company's engineering activities.

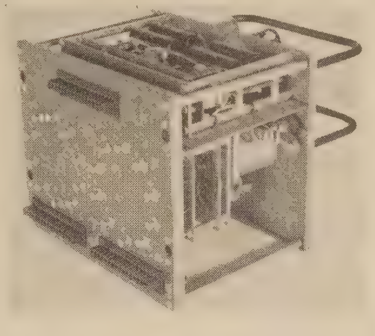
Research and engineering were previously combined under W. W. McDowell, formerly vice president for research and engineering, who was appointed resident vice president for IBM's operations in Endicott, N. Y.

Dr. Piore joined IBM in 1956. He previously was vice president in change of research for the Avco Manufacturing Co. From 1946 to 1955, Dr. Piore was with the Office of Naval Research, becoming ONR's chief scientist. He is a member of President Eisenhower's Science Advisory Committee.

Palmer, an electrical engineering graduate of Union College, Schenectady, N. Y., joined IBM in 1932 at Endicott, N. Y. He subsequently served in various managerial positions in the company's engineering and research operations.

Multiple Circuit Switch

A new, simplified method of switching multiple circuits in television broadcasting operations has been announced by **Telecontrol Corp.**, 1418 W. 166th St., Gardena, Calif.



The new "building block" switching systems design permits simultaneous multiple circuit switching, with a reduced investment in switching equipment. The basic switching modules can be applied to all television switching operations, including studio, master control and distribution switching systems.

Key to the switching module concept is a new type of multiple circuit rotary stepping switch. The remotely controlled switch is adaptable to various methods of control within television broadcast installations of all sizes.

Telecontrol switching modules have a number of inherent advantages over video relays of transistor-diode switching assemblies, according to the firm. Switching is accomplished within a one-inch radius, designed for video switching with extremely low capacitance. This results in low cross-talk and flat frequency response, even when a large number of modules are employed.

The stepping switch can handle simultaneous switching of various combinations of video, sync, audio, control and tally circuits within the same module. It also utilizes a wide range of control flexibility in remote positioning, including pulse control, rotary selector control and pushbutton selection.

Another advantage of the Telecontrol switching concept is that it permits high-speed off-air switching, with rotation to the extreme position in the order of 0.05 seconds.

Distribution switching modules (Series VSA, VSB, VSC) are designed for video distribution exchange systems, house monitoring systems and other applications where off-air pre-selection is permitted.

The distribution modules offer a number of advantages over conventional patching methods, which require a large number of circuit connections, the services of a skilled operator and time for set-up. Remote control switching with the Telecontrol modules sharply reduces the number of required circuit feeds, releases the op-

(Continued on page 168A)

Engineers:
There's new
opportunity at Link

Among the opportunities at Link, Binghamton, are:

DIGITAL COMPUTER ENGINEERS

Several senior staff engineer and senior electronic engineer opportunities have been created by the formation of the new Digital Systems Development Department.

Assignments will include the evaluation of digital systems, covering the responsibility for development project design groups. Important technical contributions will include development work on "NOR" Logic, Direct-Coupled Transistorized Logic, and other techniques for future digital projects.

Requirements include minimum BSEE or BS (Physics) with experience in digital systems design and computer check-out, and/or transistor circuit design.

SENIOR STAFF ENGINEER

To prepare, coordinate and evaluate proposals for contract sponsorship of development programs; assist laboratory manager in evaluating ideas for company sponsored development; investigate new product areas for marketability, investment and present Link capability to government and industrial concerns.

Minimum BSEE with advanced work in communications. MSEE (communications) preferred.

Experience must include 10-12 years in electronic system and hardware design and a broad background in several related areas including: early product design experience in military electronics; design of custom electronic products for commercial aviation.

If you are an electronics engineer with an eye towards a brighter, more rewarding future, why not write or submit your resume—in complete confidence—to Mr. C. P. Darrah.

GP
LINK DIVISION
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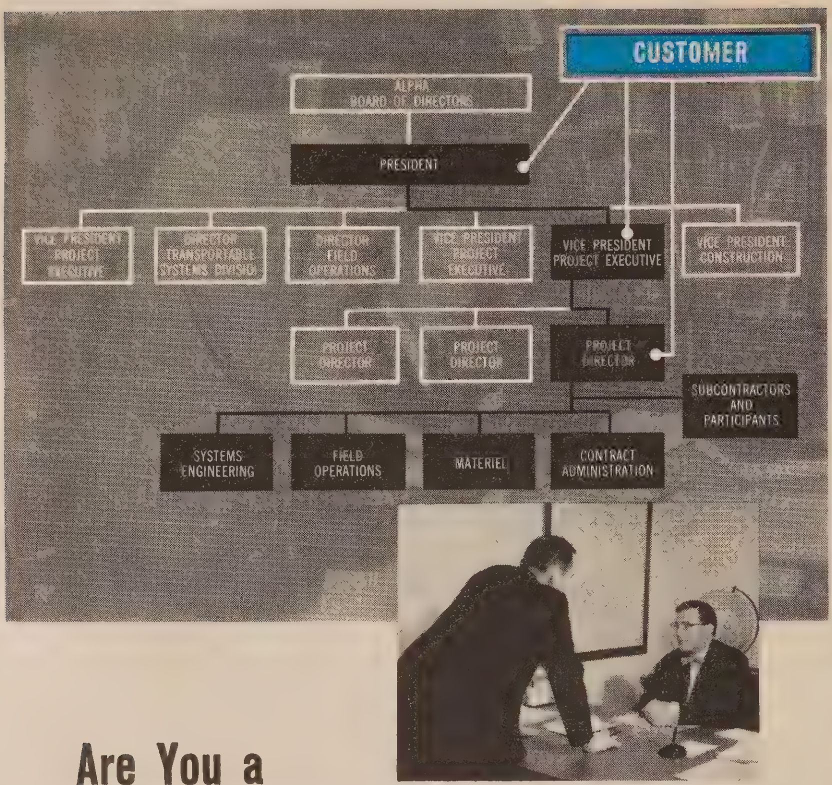
BINGHAMTON, NEW YORK

alpha is a systems management organization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Are You a Systems-oriented Engineer?

Simple and clear-cut, Alpha's internal organization is aligned to provide systems coordination by means of vertical integration of management, engineering, and administration of each project within the division to which the project is assigned. Each project division is under a Vice President and Project Executive who is organizationally a part of the central management of Alpha. Functionally, the Project Director, together with the project's own engineering, operations, materiel, contract administration, and business development personnel, deals directly with the customer and has complete authority, responsibility, and accountability for the timely execution of the project.

Does this team-oriented attitude that engenders effective interfacing relationships and intra-team communications appeal to you? Do you have systems-oriented technical talent with the specialized capabilities needed to determine system parameters; integrate a complex of equipments; direct subsystems suppliers? Write:

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a Subsidiary of Collins Radio Company

SYSTEMS DESIGNERS, ENGINEERS, CONSTRUCTORS, WORLD-WIDE • RICHARDSON, TEXAS • TELEPHONE DALLAS ADams 5-2331

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 167A)

erator for other assignments and reduces total setup time to seconds.

Ten or 20 inputs are standard for all distribution and program switching modules. For switching NTSC color video and for large video distribution exchanges, special compensated switching modules are available with built-in equalized impedance and phase shift compensation.

Modular In-Line Switch

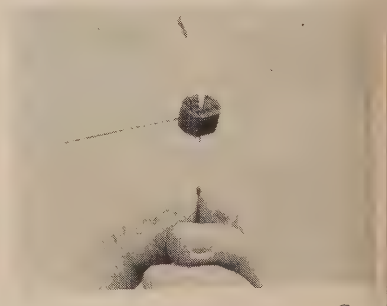
The Digitran Co., 660 So. Arroyo Parkway, Pasadena, Calif., announces a new panel switch concept (the new 7300 Series). The Digiswitch replaces ten-position, or octal, switch units of the rotary type. Panel space requirements are reduced so that designers can mount four times as many Digiswitches in the normal space required for rotary switch elements.

The switch is finger controlled and provides for ten-position, single-pole and double-pole, binary coded decimal with variations, and octal 0, 1, 2, 4 coded outputs. Internal lighting of the readout and color coding of the switch tabs are also available.

The in-line readout is said to reduce reading errors and simplify switch setting. The unit finds its applications in automation, automatic control systems, computer designs and other systems which require the setting of numerical constants or coefficients.

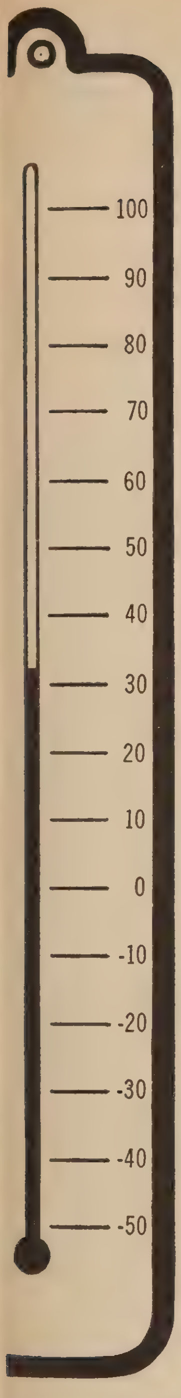
The Digiswitch is designed in switch modules which permit ganging in any desired number. For descriptive data sheet No. 7300, write to the firm.

Current Sampling Transformer



Valor Instruments, Inc., 13214 Crenshaw Blvd., Gardena, Calif., has introduced the IST series of seven pulse cur-

(Continued on page 170A)

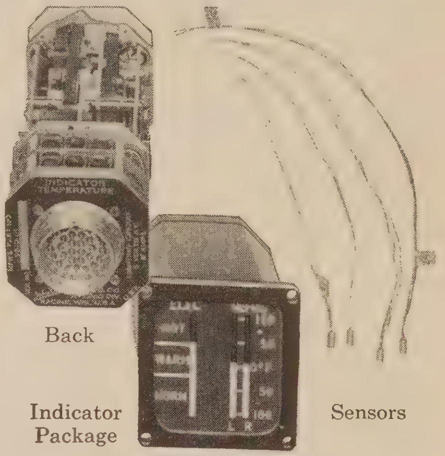


1 or 6 . . .

How do you take the temperature of an electronic system?

Use ONE Compact, Accurate, Lightweight, Completely Transistorized Oster-Developed Temperature Indicating System. Replaces 6 Indicating Systems.

The device illustrated senses and displays the highest of 4 temperature sensor signals on the Convair B-58 supersonic bomber. It also reads out the temperature of the plane's 2 refrigeration systems. However, the unit can monitor temperature of any military or commercial electronic system. Special versions can be furnished to monitor any analog voltage signal.



Back

Indicator Package

Front

Sensors

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Entire unit (component parts illustrated) has an accuracy of 1½%, weighs only 3.85 lbs. max., requires only 2⅜″ panel space, and does the work of 6 indicating systems. Component parts consist of 4 sensors, a computer package with 6 channels, and a hermetically sealed indicator package.

The unit is typical of Oster designed equipment.

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For help with your instrumentation and display problems, talk to the specialists at the Avionic Division.

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Engineers For Advanced Projects: Interesting, varied work on designing transistor circuits and servo mechanisms.
Contact Mr. Robert Burns, Personnel Manager, in confidence.

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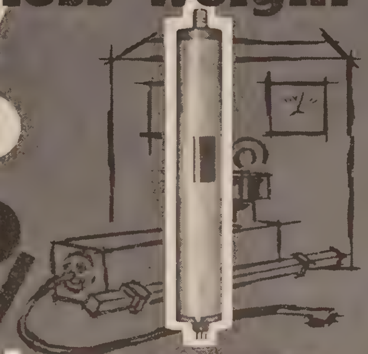

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Periodic Permanent Magnet Oscillator

Huggins again demonstrates leadership in TWT production with a Backward Wave Oscillator focused in a periodic permanent magnet structure. This development opens a wide range of new uses for the BWO. With no cooling required, all need for auxiliary power is completely eliminated. Savings in size and weight are impressive. An 11½″ x 2½″ capsule, weighing 3.5 pounds replaces a solenoid and power supply weighing approximately 50 pounds.

HO 22 SPECIFICATIONS

Frequency	Min. Power Output
8.5 to 12.0 KMC	10 dbm
8.2 to 12.4 KMC	5 dbm

Tuning voltage range is 400 to 1800 volts.
(Further details on request)

There are opportunities at Huggins for qualified personnel. Write to Richard A. Huggins, President.

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999 East Arques Avenue · Sunnyvale, California
REgent 6-9330

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(Continued from page 168A)

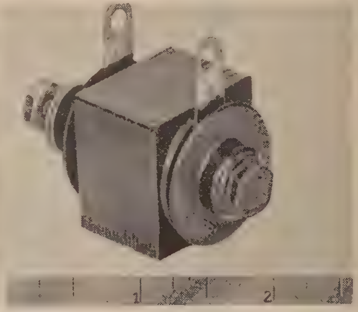
rent sampling transformers which deliver synchronizing voltage pulses for use with radar transmitters or other devices which develop high pulse currents. The voltage pulses have the same shape as the high current pulses. No resistance is added to the circuit because the transformer is not connected to the current carrying the conductor; voltage pulses are developed by passing the conductor through the hole in the transformer. This new approach eliminates the resistive networks used in conventional methods.

Specifications: Size $\frac{9}{16} \times \frac{1}{2} \times \frac{3}{8}''$; Weight $\frac{1}{8}$ ounce; Ratio 20:1 to 150:1; Pulse Widths 0.4 to 3.0 μsec at 50 volts; Inductance 0.12 to 6.0 MH; Optimum Load 50 to 500 ohms; Meets MIL T27A.

Price: 1–4 units $7.70 each; $4.60 each for 100. Delivery: From stock typically; two weeks maximum.

Silicon Rectifiers Surge Protector

Type SP Surge Protectors manufactured by **Electric Products Division, Dept. 502P, Vickers Incorporated,** 1815 Locust St., St. Louis 3, Missouri, protect silicon power rectifiers from breakdown due to transient high voltage.



Non-linear resistance, decreasing with increase in voltage, plus built-in capacitance, absorbs intermittent surge energy up to 3000 watts, limiting voltage to safe value for silicon rectifier. Consumes less than 5 watts under steady-state conditions.

Nine standard types cover the range of 50 to 600 volts normal PIV rating. Field tested for more than a year; laboratory surge tested for more than 5 million cycles.

For information write to the firm.

(Continued on page 174A)

Use Your
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It's Valuable

Very Small Wire

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MOUNT VERNON, N.Y.

Unusual and difficult engineering problems may be solved, at times, by single or multiple electroplating of small wires . . . A wide variety of metals is available, both as the core wire and as the plate. Inquiries invited.

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with compact, transistorized series

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STANDARDS**

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his series brings together a combination of ultra-
able glass sealed crystals, matched-design sili-
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roportional control oven performance. The result
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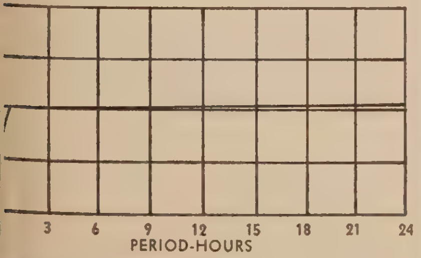
ormal conditions.



or information, write stating your requirements.
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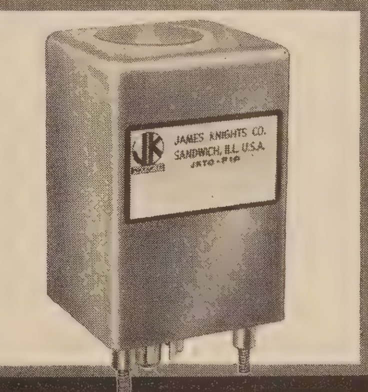

SPECIFICATIONS

FREQUENCY: 1 to 5 mc. is standard. Other frequencies available on special order.
OVEN: Transistorized, proportional control.
OUTPUT: One V into 5000 ohms.
POWER: Operates from 24 to 28V D.C.
DIMENSIONS: 2" x 1.84" x 2⅞" H.
WEIGHT: 10 Oz. Maximum.
ENVIRONMENTAL: Hermetically sealed, shock and vibration resistant.
TEMPERATURE RANGE: From −55°C to +75°C. Also from −55°C to 100+°C.

PRODUCTS

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in
voltage
regulated
dc
power
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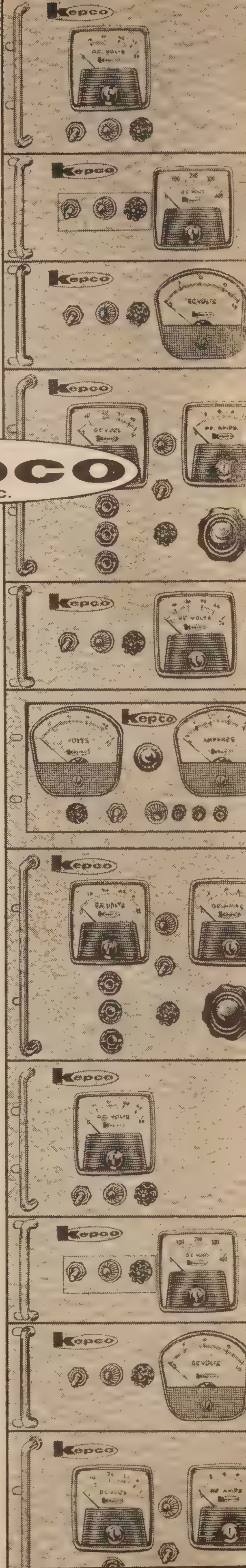


FREQUENCY STANDARDS

PRECISION FORK UNIT
TYPE 50

Size 1" dia. x 3¾" H. Wght., 4 oz.*

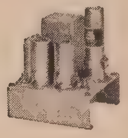
Frequencies: 240 to 1000 cycles
Accuracies:—
Type 50 (±.02% at —65° to 85°C)
Type R50 (±.002% at 15° to 35°C)
Double triode and 5 pigtail parts required
Input, Tube heater voltage and B voltage
Output, approx. 5V into 200,000 ohms

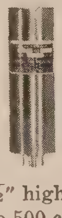
*3⅛" high
400 - 1000 cy.

FREQUENCY STANDARD
TYPE 50L

Size 3¾" x 4½" x 5½" High
Weight, 2 lbs.

Frequencies: 50, 60, 75 or 100 cycles
Accuracies:—
Type 50L (±.02% at —65° to 85°C)
Type R50L (±.002% at 15° to 35°C)
Output, 3V into 200,000 ohms
Input, 150 to 300V, B (6V at .6 amps.)





PRECISION FORK UNIT
TYPE 2003

Size 1½" dia. x 4½" H. Wght. 8 oz.*

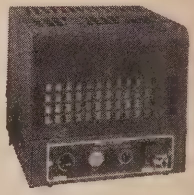
Frequencies: 200 to 4000 cycles
Accuracies:—
Type 2003 (±.02% at —65° to 85°C)
Type R2003 (±.002% at 15° to 35°C)
Type W2003 (±.005% at —65° to 85°C)
Double triode and 5 pigtail parts required
Input and output same as Type 50, above

*3½" high
400 to 500 cy.
optional

FREQUENCY STANDARD
TYPE 2005

Size, 8" x 8" x 7¼" High
Weight, 14 lbs.

Frequencies: 50 to 400 cycles (Specify)
Accuracy: ±.001% from 20° to 30°C
Output, 10 Watts at 115 Volts
Input, 115V. (50 to 400 cycles)



FREQUENCY STANDARD
TYPE 2007-6

NEW

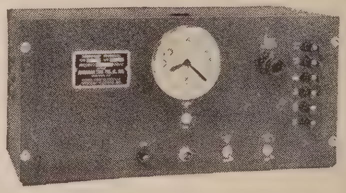
TRANSISTORIZED, Silicon Type
Size 1½" dia. x 3½" H. Wght. 7 ozs.

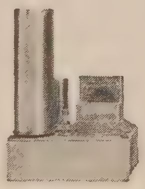
Frequencies: 400 — 500 or 1000 cycles
Accuracies:
2007–6 (± .02% at —50° to +85°C)
R2007–6 (±.002% at +15° to +35°C)
W2007–6 (±.005% at —65° to +125°C)
Input: 10 to 30 Volts, D. C., at 6 ma.
Output: Multitap, 75 to 100,000 ohms

FREQUENCY STANDARD
TYPE 2121A

Size
8¾" x 19" panel
Weight, 25 lbs.

Output: 115V
60 cycles, 10 Watt
Accuracy:
±.001% from 20° to 30°C
Input, 115V (50 to 400 cycles)





FREQUENCY STANDARD
TYPE 2001-2

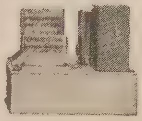
Size 3¾" x 4½" x 6" H., Wght. 26 oz.

Frequencies: 200 to 3000 cycles
Accuracy: ±.001% at 20° to 30°C
Output: 5V. at 250,000 ohms
Input: Heater voltage, 6.3 - 12 - 28
B voltage, 100 to 300 V., at 5 to 10 ma.

FREQUENCY STANDARD
TYPE 2111C

Size, with cover
10" x 17" x 9" H.
Panel model
10" x 19" x 8¾" H.
Weight, 25 lbs.

Frequencies: 50 to 1000 cycles
Accuracy: (±.002% at 15° to 35°C)
Output: 115V, 75W. Input: 115V, 50 to 75 cycles.



ACCESSORY UNITS
for TYPE 2001-2

L—For low frequencies multi-vibrator type, 40-200 cy.
D—For low frequencies counter type, 40-200 cy.
H—For high freqs, up to 20 KC.
M—Power Amplifier, 2W output.
P—Power supply.

This organization makes frequency standards within a range of 30 to 30,000 cycles. They are used extensively by aviation, industry, government departments, armed forces—where maximum accuracy and durability are required.

WHEN REQUESTING INFORMATION
PLEASE SPECIFY TYPE NUMBER

American Time Products, Inc.

Watch Master
Timing Systems

Telephone: PLaza 7-1430

580 Fifth Ave., New York 36, N. Y.

Fits in an 8¾" slot
Beckman/Berkeley
FREQUENCY METER
MODEL 7175

Measure 10cps to 110Mc with one compact meter

Comprehensive range for only $1895. Never before has so broad a range been offered for so low a price—a combination made possible by closely integrating a simple heterodyne converter with a top-notch 10Mc counter. Frequencies up to 10Mc are measured by direct counting. To measure frequencies above 10Mc, the operator simply rotates reference frequency selector until panel meter shows strong deflection, then reads counter indication. Measurements take less than a minute to make. Accuracy far exceeds FCC requirements over communications range. Possible error is .00004% or less from 1Mc to 110Mc.

Write for technical bulletin on Model 7175.

Frequency measuring range
10cps to 110Mc
Sensitivity
100mv rms into 1M ohms up to 10Mc
100mv rms into 100 ohms up to 110Mc
Accuracy
Oscillator accuracy ± 1cps
Oscillator stability
3 parts in 10^7 per week
Recording facility
Rear jack carries code signals to actuate Beckman printer
Dimensions:
8¾" x 19" panel, 17" deep
Weight
Ready for rack: approx. 47 lbs.
In cabinet: approx. 60 lbs.
Price $1895

INSTRUMENTAL IN YOUR FUTURE 25 YEARS 1935-1960

Beckman®

Berkeley Division
Richmond, California

T24

new!

Min Rac 17

miniature rack & panel connectors with POKE HOME® contacts

Solve space, weight and size problems with AMPHENOL's new Min Rac 17 connectors, true miniatures with the "Big Plus" advantage of Poke Home contacts! Min Rac 17's are rack & panel connectors ideally suited for today's compact chassis designs, connectors half the size and weight of standards, delivering full size efficiency. And with the patented Poke Home contact concept (U.S. Pat. 2,419,018), Min Rac 17's are easily, reliably assembled—contacts are crimped or soldered outside the connector body, then "poked home" for assembly.

Min Rac 17's are available in 9, 15, 25, 37 and 50 contacts in rack & panel, cable-to-chassis and cable-to-cable designs. Contacts are gold plated. Shells may be ordered with clear chromate or gold iridite finish.

These remarkable connectors are available now—write for full catalog!

AMPHENOL CONNECTOR DIVISION

1830 S. 54th AVE., CHICAGO 50, ILLINOIS

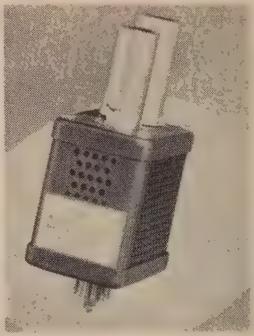
Amphenol-Borg Electronics Corporation

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 170A)

Peaked Amplifier

CES Electronic Products, Inc., P.O. Box 7504, San Diego 7, Calif., has announced development and production of a new peaked amplifier in the 15 to 2000 cps range.



The new unit, Model 107-B, is a three stage direct-coupled amplifier with a CES Twin-T Filter in the negative feedback loop. The filter gives at least 50 db insertion loss at its balance frequency and the normal feedback is at least 70 db. This retains 20 db feedback for stabilization at the peaked frequency and results in a very sharp, deep-shouldered response curve. The performance of the amplifier is independent of the driving point impedance and can be terminated in any high impedance load. Q's of 100 are attainable with excellent stability.

According to the company, the amplifier is available in standard models for frequencies from 15 to 2000 cps. Special models with frequencies as low as 0.01 cps can be supplied on special order.

For additional information, write to the firm.

Rotary Solenoids And Stepping Motors

A new application guide to Ledex rotary solenoids, selectors and Syncramental stepping motors has just been issued by **G. H. Leland, Inc.,** 123 Webster St., Dayton, Ohio.

This eight-page bulletin (No. A-1259)—illustrated with line drawings, charts, photographs and circuit diagrams—contains specific physical, performance and environmental data on more than 250 different models available for immediate delivery. It also supplies information on how to use this data to select the proper rotary solenoid, selector or Syncramental stepping motor for any application.

Only half the size of ordinary units Leland's highly efficient Ledex rotary solenoid is capable of developing twice a much power as these ordinary solenoids.

Its stepping and selector switch—

(Continued on page 176A)

Instantly, two million watts will blast the Navy's radio signal anywhere on earth: to our planes, ships and submarines on patrol . . . wherever they may be.

Continental Electronics

This new VLF transmitter is the world's most powerful. With it, the U. S. Navy again knows it is getting the best, from the specialists in super power radio!

Give your products
MORE RELIABILITY and
BETTER PERFORMANCE with
FREED
QUALITY
AVAILABLE FROM STOCK

MINIATURE AUDIO TRANSFORMERS to MIL Specifications

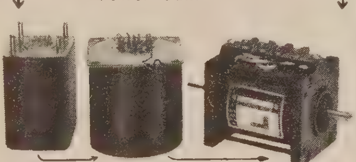
- Hermetically sealed Grade 4.
- Frequency response:
± 2DB 30-20,000 CPS
*± 2DB 200-10,000 CPS

Cat. No.	Imped. level —	Appl.	MIL Type
PMA 1	Pri. 50/200/500 Sec. 60,000 C.T.	Line or mike to single or P.P. grids	TF4RX10YY
PMA 2	Pri. 4/8 Sec. 60,000 C.T.	Dynamic mike or spkr. voice coil to single or P.P. grids	TF4RX10YY
PMA 3	Pri. 50/200/500 Sec. 60,000 C.T.	Line or mike to single or P.P. grids	TF4RX10YY
PMA 4	Pri. 15,000 Sec. 60,000 C.T.	Single triode plate to single or P.P. grids	TF4RX15YY
PMA 5*	Pri. 15,000 Sec. 60,000 C.T.	Single triode plate to P.P. grids	TF4RX15YY
PMA 6	Pri. 15,000 Sec. 50/200/500	Single triode plate to multiple line	TF4RX13YY
PMA 7*	Pri. 15,000 Sec. 50/200/500	Single triode plate to multiple line	TF4RX13YY
PMA 8	Pri 30,000 C.T. Sec. 50/200/500	Push-pull triode plate to multiple line	TF4RX13YY
PMA 9	Pri. 60,000 C.T. Sec. 50/200/500	Crystal mike or pickup to multiple line	TF4RX13YY
PMA 10	Pri. 50/200 Sec. 50/200/500	Mixing or matching	TF4RX16YY
PMA 11	40 hy, 3 ma. d.c. 3500 Ω d.c. res.	Parallel feed reactor	TF4RX20YY

MAGNETIC AMPLIFIERS

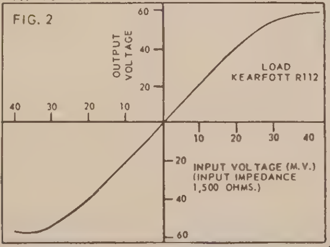
- Hermetically Sealed To MIL Specifications
- No Tubes
- Direct Operation from Line Voltage
- Fast Response
- Long Life Trouble Free Operation
- Phase Reversible Output

Power Gain 2 x 10⁸



Transistor Preamp. MAT-1 Wt. 10 oz.
Mag. Amp. MAF-5 Wt. 18 oz.
Motor

FIG. 2



WRITE FOR FURTHER INFORMATION ON THESE UNITS OR SPECIAL DESIGNS.
Partial listing only—Send for NEW 48 page transformer catalog. Also ask for complete laboratory test instrument catalog.

FREED TRANSFORMER CO., INC.
1720 Weirfield St., Brooklyn (Ridgewood) 27, N.Y.

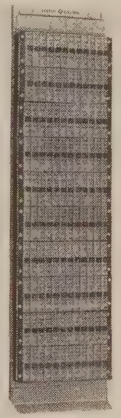
These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Contnued from page 174A)

which can be manufactured in hermetically-sealed containers—has replaced the use of numerous ordinary relays in many applications where space and weight present a problem. Ledex stepping and selector switches require only one-fifth the space formerly taken up by ordinary relays.

A versatile, high-precision, bi-directional stepping motor, the Ledex Syncramental motor develops at least three times greater torque than comparable devices can provide. During its design life of 2,000,000 steps in each direction, the probability of its missing a step is only 1 in 1,000,000.

600-Channel Transistorized Multiplex Carrier



General Electric Co., Communication Products Dept., Lynchburg, Va., announced today that it has developed a transistorized multiplex-carrier system capable of handling up to 600 voice frequency channels on a single radio beam.

Fully transistorized, the new General Electric single sideband suppressed carrier system has toll quality capable of meeting international and domestic long-distance standards.

In the new multiplex-carrier, reliability is enhanced by the use of a technique which utilizes a standby component for each component in the common equipment, such as amplifiers and master oscillators. Upon failure of an individual part, the parallel component keeps operating, with no switching delay to seriously affect data transmission."

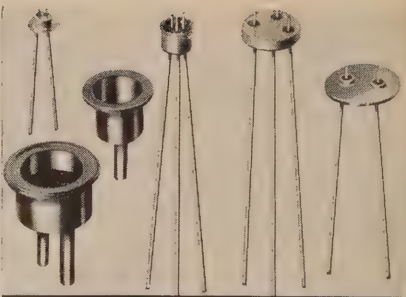
Also achieved is a substantial reduction in power drain. Typical equipment currently available requires thousands of watts for a system utilizing 240 channels. This design takes less than 700 watts for the corresponding capacity.

Despite the increase in capacity which makes 600 channels available, this unit is one-third the size of conventional tubed equipment. G-E's design makes possible 120 channels in an eight-foot space where only 24 channels previously could be accommodated.

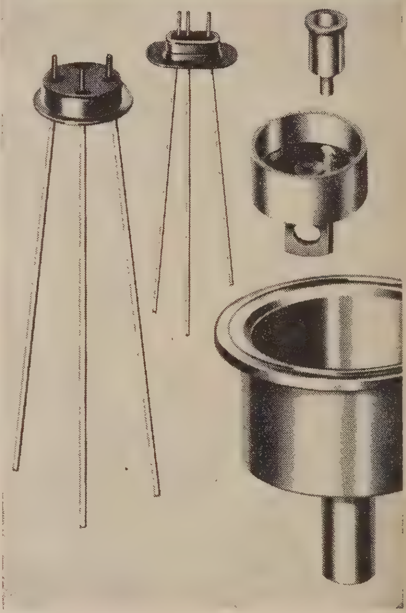
Computer Grade Electrolytics

A new four-page catalog describing Type QE computer grade electrolytic capacitors is available from **Aerovox Corp.,**

(Continued on page 178A)



Quality
Is The Constant In
GLASS-TITE
HERMETIC SEALS



Glass-Tite's story is simple and successful. They make a custom seal to your most minute specifications or they supply standard glass-to-metal seals — either way they make only one quality . . . THE BEST. No design requirement is too tough, no reasonable delivery date is impossible.

Specify Glass-Tite in Kovar and compression seals, diodes and rectifier enclosures for the semi-conductor industry and all electronic applications.

Write Dept. 729 for literature and send details of your design requirements.

563-9

GLASS-TITE
INDUSTRIES, INC.
725 BRANCH AVENUE
PROVIDENCE, R. I.

Spincasting

A significant contribution to Antenna Technology by D. S. KENNEDY & CO.

Kennedy engineers and scientists have successfully applied a simple scientific principle to the manufacture of large antennas. The application of this principle that "the surface of a liquid when spun about a vertical axis assumes a paraboloidal shape" will result in several important benefits.

First, surface accuracy of antennas should improve by more than an order of ten. This is possible even though the surface to which the liquid is spuncast is irregular, because such irregularities in the container in no way affect the smooth accuracy of the surface of the liquid.

This means substantial savings in time and money in the manufacture of antenna dishes of this accuracy, as well as antennas of greater efficiency.

There is no theoretical limit to the size of dish Kennedy may be able to Spincast. Dishes up to 10 feet in diameter are already in production and Kennedy is ready to receive inquiries as to the application of this technique to your problems. For complete information write, wire or call collect — EVergreen 3-1200.

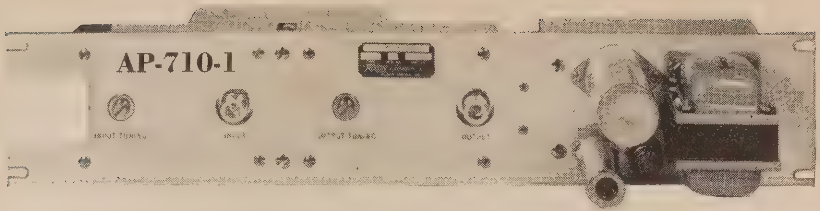
D. S. KENNEDY & CO.

TRACKING ANTENNAS • RADIO TELESCOPES
RADAR ANTENNAS • SCATTER COMMUNICATIONS ANTENNAS
MICROWAVE RESEARCH AND DEVELOPMENT
TRANSMISSION TOWERS • SWITCHYARD STRUCTURES

Antenna Division
Cohasset, Massachusetts
EVergreen 3-1200

Anchor Metals Division
Hurst, Texas
(Fort Worth) ATlas 4-2583

Advanced Engineering Division
Monterey, California
FRontier 3-2461



SAVE VALUABLE COMMUNICATION DOLLARS
with RIXON'S LOW NOISE PREAMPLIFIERS

Much effort has been made and is being expended to reduce "noise" in receiving systems because of the potential dollar savings resulting from improved receiver performance. Even if the "noise" does not materially effect the performance of the receiving system, if there is a long transmission line between the antenna and the receiver, the signal power is reduced by the transmission loss in the line.

The Rixon 400-500 mc preamplifier, shown here, with noise figures in the 4 to 5 db-range, makes a major improvement when placed in front of a 10 to 12-db commercial receiver. It's the same as a four time increase in transmitter power.

Other Rixon Preamplifier Models are available on short notice and are easily adapted at the factory to cover any band in the 10-500 mc frequency range.

SPECIFICATIONS

AP-710-1 UHF

Frequency Range	400 to 500 mc
Noise Figure	3.5 db to 5.5 db*
Gain & Bandwith	21 to 23 db—2 mc
Input & Output Impedance	50 ohms
Max. Input Level	100 mv
Panel Size & Wt.	3½ of 19-in. Rack Space—9¾ lb.
RF Connectors	Type 'N'
Power	115 vac, 50-60 cps, 15 watts
Tube Type	7077 Ceramic Triode
Circuit	Grounded-grid, 2 stages
Tuned Circuits	Three continuously tunable coaxial cavities of rigid brass tubing. Simple peaking adjustment only.

*Depending on tube selection

RIXON ELECTRONICS, INC.
2414 Reedie Dr., Silver Spring, Md. • LO 5-4578

---

tubes and semi-conductors.

Over 5000 types always in stock at E. T. S.,

world's largest tube and transistor specialist. Special purpose, Transmitting, Receiving. All important brands. Name the type, name the brand, name the quantity—we have it. Famous nationwide service—fast delivery anywhere. *Get your free subscription to the E.T.S. Bulletins* for authoritative, up-to-date new-item and new-availability news—write on your company letterhead today.

ELECTRONIC TUBE SALES INC.
74 Cortlandt St., New York 7, N.Y. BArclay 7-4140 TWX-NY1-4042

LAB

Model 802B Twin Transistorized Supply

EACH OUTPUT:
0-36 VOLTS
0-1.5 AMPERES

PRICE: $580.00

LINE REGULATION: Less than 5.0 millivolts
LOAD REGULATION: Less than 5.0 millivolts
RIPPLE AND NOISE: Less than 200 µv rms
SERIES CONNECTED: 0-72 volts, 0-1.5 amperes

OUTPUT CONTINUOUSLY VARIABLE
REMOTE ERROR SENSING
AUTOMATIC OVERLOAD PROTECTION
CONVECTION COOLING: No moving parts

HARRISON LABORATORIES, INC.
45 INDUSTRIAL ROAD • BERKELEY HEIGHTS, NEW JERSEY • CR 3-9123

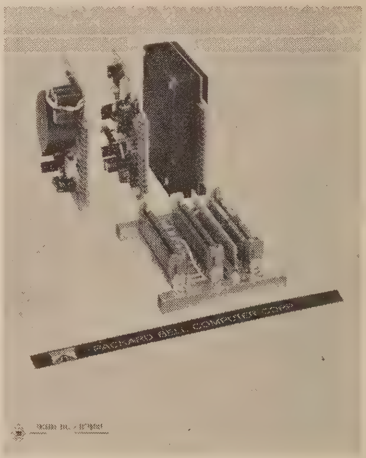
These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 176A)

New Bedford, Mass. Literature provides complete technical information on these high reliability units including dimensional drawings, performance characteristics and table of stock values. Copies may be had by writing to the firm for QE Bulletin NPJ-110.

DC Amplifier

Packard Bell Computer Corp., a Division of Packard Bell Electronic Corp., 12333 West Olympic Blvd., Los Angeles 64, Calif., announces a completely solid-state DC amplifier, designated the DCA-1-B, which has the modularized plug-in feature illustrated in the photograph. This feature combined with the small size (4¾″ × 3½″ × 4¼″) permits greater design flexibility as it enables the design engineer to incorporate the amplifier in either a standard or nonstandard case.



The DCA-1-B is an operational, wide band, high accuracy amplifier with a solid-state chopper. Solid state design and the use of a non-mechanical chopper are said to make this a reliable instrument.

Specifications include: Frequency response exceeding −3 db at 200 kc; gain accuracy of ±0.03%; linearity and stability at ±0.02%; and drift of 500 µv referred to input.

Photoelectric Pulse Generator

A shaft-driven device that delivers electrical pulses at its output terminals is available from **W. & L. E. Gurley, Industrial**

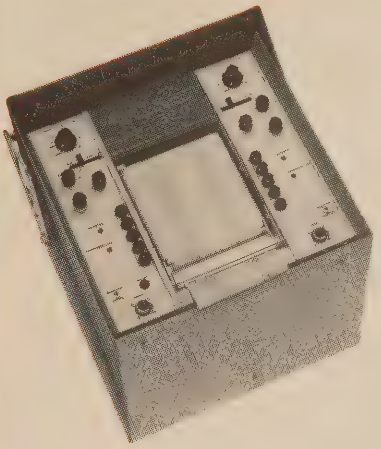
(Continued on page 180A)

Use Your
IRE DIRECTORY!
It's Valuable

keep an accurate graphic record

OF RESEARCH, DESIGN,
TEST DATA

two channels



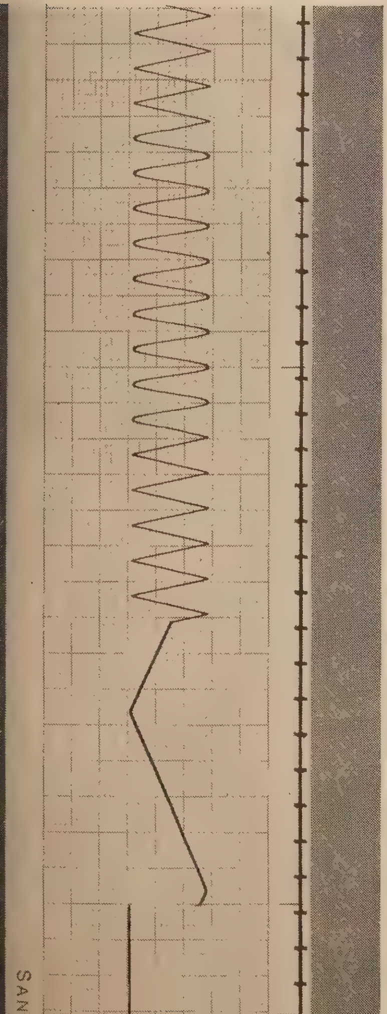
For General Purpose
DC Recording — Model 320

For recording *two variables* simultaneously, the Model 320 provides a versatile, transistorized amplifier for each input signal. The rugged 2-channel recorder assembly has heated stylus recording on two *50 mm wide* rectangular coordinate channels, 4 pushbutton chart speeds, and 6 inches of visible chart. The Recorder can be placed vertically, horizontally or at a 20° angle.

MODEL 320 SPECIFICATIONS

Sensitivity: 0.5, 1, 2, 5, 10, 20 mv/mm and v/cm
Frequency Response: 3 db down at 125 cps, 10 mm peak-to-peak
Common Mode Voltage: ±500 volts max.
Common Mode Rejection: 140 db min. DC
Calibration: 10 mv internal ±1%
Output Connectors for each channel accept external monitoring 'scope or meter

W SANBORN PORTABLE DIRECT WRITING RECORDERS FOR IN-PLANT, LABORATORY OR FIELD RECORDING



Two models of this 21 lb. brief case size recorder are available — Model 301 for AC strain gage recording, Model 299 for general purpose DC recording. Both provide immediately visible, inkless traces by heated stylus on 40 division rectangular coordinate charts . . . frequency response to 100 cps . . . 5 and 50 mm/sec chart speeds . . . approx. 4 inches of record visible in top panel window.

single channel

MODEL 301 SPECIFICATIONS

The amplifier section of the Model 301 is an all-transistorized carrier type with phase sensitive demodulator. The power supply and internal oscillator circuits are also transistorized.
Sensitivity: 10 uv rms/div (from transducer)
Attenuator Ratios: 2, 5, 10, 20, 50, 100, 200
Carrier Frequency: 2400 cps internal
Transducer Impedance: 100 ohms min.
Calibration: 40 uv/volt of excitation
Output Connector: for external monitoring 'scope or meter

MODEL 299 SPECIFICATIONS

Combines the dependability of transistors with the high input impedance of vacuum tubes for reliable broad-band DC recording.
Sensitivity: 10, 20, 50, 100, 200, 500 mv/div and 1, 2, 5 and 10 v/div
Input Resistance: 5 megohms balanced each side to ground
Common Mode Voltage: ±2.5 volts max. at 10 mv/div sensitivity increasing to ±500 volts max. at other sensitivities
Common Mode Rejection: 50:1 most sensitive range
Calibration: 0.2 volt internal ±1%
Output Connector: for external monitoring 'scope or meter

Contact your Sanborn Sales-Engineering representative for complete information, or write the main office in Waltham. Sales-Engineering representatives are located in principal cities throughout the United States, Canada and foreign countries.

SANBORN COMPANY
INDUSTRIAL DIVISION
175 Wyman Street, Waltham 54, Mass.

I want a "Whatcha-ma-call-it?"

It's a "thinga-ma-jig that ......"

How often have you struggled to remember the name of a component or electronic item. . . . Just could not think quickly what it is called?

YOU CAN FIND IT
IN THE IRE DIRECTORY!

because

(1) The IRE Directory classifies products by purpose and use.

(2) Its listings are fundamental—the way an engineer thinks.

(3) "Terminology" is cross indexed in the pink pages—condensed, simple, not mixed in with firm names.

(4) Ads face listings thus helping to identify products by actual pictures.

(5) Product code numbers reduce complex and duplicate listings, saving you "searching" time and effort.

Study it . . . save it . . . work it.

®

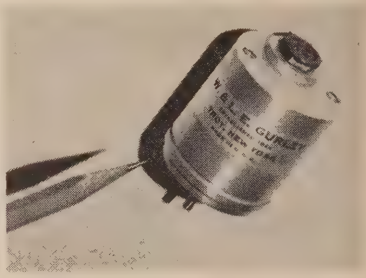
THE INSTITUTE OF RADIO ENGINEERS
1 East 79th Street, New York 21, N.Y.

NEWS
New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 178A)

Division, Troy, N. Y. The Model 8601 Photoelectric Pulse Generator may be used either as a rate generator or as an angle-measuring unit.



When used as a rate generator, the output frequency is read in terms of shaft speed. When used to measure angles, the total angle is determined by totalizing individual pulses. The pulses are generated by a light which passes to a photocell through rotating disc with alternating clear and opaque sectors. The number of pulses per revolution, therefore, is a function of the number of segments on the disc.

The Gurley Generator can be supplied

(Continued on page 183A)

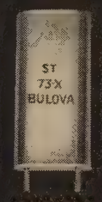
How to Step Up
PRODUCTION and
LOWER the COST of

COIL
WINDING

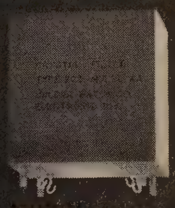
SHOW ROOM
114 Liberty St.
New York 6, N.Y.
Demonstration by
Appointment or
Send Your
Specifications to

AUMANN
High Precision

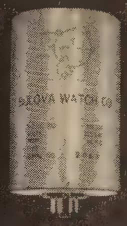
INDUSTRIAL
WINDING MACHINERY
CORPORATION
P.O. Box 62, New York 5, N.Y.
WHitehall 3-1754



CRYSTALS
Available for any frequency from 2 KC thru 100 mc. to meet and exceed all military specifications.

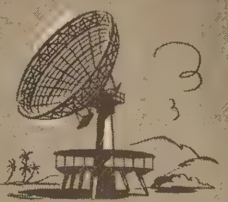


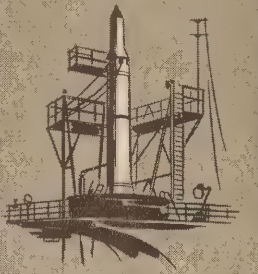
CRYSTAL FILTERS
Center frequencies from 10 KC thru 20 mc. band widths of .01% to 8% of center frequency.



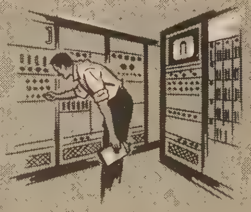
OVENS
Complete from multi-purpose AM 100 to the specific BHC series, temperature stabilization to 1°C.

PACKAGED OSCILLATORS
30 cps thru 70 mc frequencies available as tube type or transistorized oscillators.





BULOVA



NUMBER ONE SOURCE

in frequency control—components and systems

Today, an increasing number of electronic systems demand a degree of reliability heretofore unobtainable. That is why more and more manufacturers are specifying Bulova.

Bulova crystals, filters, ovens, packaged oscillators, and Bulova frequency control systems, custom-designed for either limited or mass production, meet and exceed military and industrial specifications.

Bulova's experience in mastering many of the most difficult problems involving component and system reliability has made it the *number one source* for frequency control devices. This experience can prove of immense value in your particular program. For more information write Dept. A-1183, today.

BULOVA

ELECTRONICS DIVISION • WOODSIDE 77, NEW YORK

LING'S LIGHT-ARMATURE SHAKER LETS YOU TEST UNDER PRESSURE

Altitude, temperature, humidity! To help you conduct vibration tests under such extremes, Ling brings you the new liquid-cooled Shaker A246 of revolutionary design. In this 7500 force-pound shaker, Ling shaves the weight of the armature to a new low of only 68 pounds—the lightest armature by far for this force-rating. Structural resonance, first major, develops at 2570 cps, bare table. Shaker efficiency is at a new high; the A246 delivers full output at reduced amplifier power, cutting costs on associated electronics equipment. In a chamber, it functions at extremes well above ordinary shakers—from −100°F to +300°F, and up to 125,000 ft. Further, it simplifies chamber testing even more when used with the piggy-back chamber shown above. With Ling seals and baffles, the shaker body acts as one wall of the chamber, and only the table rides into the chamber. This is just one more advance from Ling research; for electronics that always help you out of prototype into production, *fast*—look to Ling. For details, write Dept. IRE-1, at either address below.

LING
ELECTRONICS

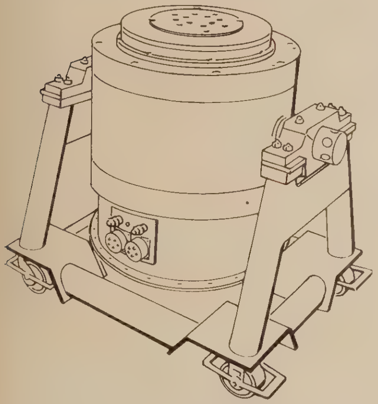
A DIVISION OF LING-ALTEC ELECTRONICS, INC. • 1515 SOUTH MANCHESTER, ANAHEIM, CALIFORNIA • 120 CROSS STREET, WINCHESTER, MASSACHUSETTS

LING ELECTRONICS

The new A246 shaker is but one of the advances growing out of Ling Electronics' continuing program of research and development. This program contributes to the many advantages enjoyed by the Ling customer—fast deliveries, sound engineering and design, ease of maintenance, and the compatibility of Ling environmental testing equipment with other systems.

The compatible design of the A246, for example, permits it to function as part of a test chamber—reducing the size of a chamber needed, and eliminating usual more costly installations. For this method, Ling also supplies a complete line of thermal barriers needed for piggy-back mounting, making combined-environment testing more practical.

Whatever your needs in high-power electronics—for vibration testing, acoustics or sonar—rely on Ling for truly practical design and advanced engineering.



Model A246 SHAKER, which is illustrated above, offers these other performance advantages: 7500 force pound rating, with high first resonance of 2750 cps. Engineered to operate continuously at maximum force on low input. Features simplified compensation over wide bandwidths, dual magnetic field structure for low stray field and improved force-current linearity.

LING ELECTRONICS • HIGH-POWER ELECTRONICS FOR: VIBRATION TESTING • ACOUSTICS • SONAR

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

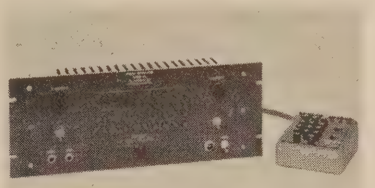
(Continued from page 180A)

with either photoresistive or photovoltaic cell. Output of the former cell consists of alternations between two levels of internal resistance; while output of the latter is a series of dc voltage pulses. Typically the output voltage is 0.1 to 0.25 v at 50K load impedance. Several standard disc patterns provide up to 500 pulses per revolution.

An illustrated bulletin is available.

Digital Translator

A new digital translator which accepts virtually any kind of digital data and provides an analog output plus control signals is now available from **F. L. Moseley Co.,** 409 N. Fair Oaks Ave., Pasadena, Calif.



The instrument, Model 42, permits automatic operation of Moseley Autograf or similar X-Y recorders. Accuracy of the digital-to-analog conversion is 0.1% and the accuracy of the recorders is maintained.

Model 42 is compatible with IBM summary punches and card readers including Models 514, 519, 523, 524, 526, etc. It may also be driven by mechanical punched tape readers such as Friden, Soroban solenoid and Teletype motorized readers, without modification to either the translator or driving equipment.

The new digital translator is supplied with a 10-key serial keyboard for manual input. The instrument accepts 4 digits and sine per axis and provides a front panel display of matrix contents.

Accessories available include a magnetic tape adapter, Flexowriter converter, remote decimal contents read-out panel and an optical magnetic tape converter.

Further information may be obtained from the firm.

Machine Tool Control Brochure Available

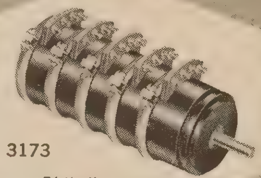
A new brochure describing numerical machine tool controls is now available from the **Industrial Systems Div., Hughes Aircraft Co.,** International Airport Station, Los Angeles 45, Calif.

The new control provides automatic positioning of a two-axis table from a preprogrammed punched one-inch tape. A third axis control can be added to the system.

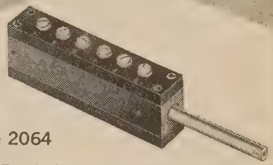
The booklet gives a complete description of the unit, which can be applied to

(Continued on page 194A)

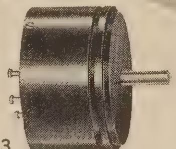
MARKITE
CONDUCTIVE PLASTIC POTENTIOMETERS



Type 3173
⅞" dia. rotary



Type 2064
Dual-element rectangular rectilinear



Type 3033
1$\frac{5}{16}$" dia. rotary

When the ultimate in quality and reliability is required . . . when there is no time for standby or interruptions . . . no room for component value variations . . . no tolerance of failure — then it's high time to specify MARKITE precision potentiometers. Here are only a few reasons why they provide performance beyond the expected:

• Linear stability for more than 50 million cycles • Substantially infinite resolution • Independent linearity to 0.05% in 1$\frac{5}{16}$" dia. units and 0.01% in 5" dia. units • Operation in ambient temperatures up to 200° C • Shock and acceleration resistance in excess of 100g • Rotational speeds up to 1,000 rpm • Meet Military Specifications.

Write for Design Data and Catalog for Rotary and Rectilinear Potentiometers.

MARKITE
CORPORATION
155 Waverly Place • New York 14, N. Y.

IMPULSE

A DIGEST OF NEW DEVELOPMENTS IN ELECTRONICS AND AUTOMATION

PUBLISHED BY **ROME CABLE DIV. OF ALCOA**, ROME, N. Y.
PIONEERS IN INSTRUMENTATION CABLE ENGINEERING

STILL A MAN'S WORLD. More attention by designers of electronic equipment to the human factor is being called for by the people handling human engineering for the Air Force. Both operation and maintenance are involved. Typical deficiencies that may unnecessarily complicate maintenance, for example, are: insufficient or inadequate check points, extensive calibration requirements and the placing of high-failure-rate components in inaccessible spots. Ultimate goal is equipment designed so that required maintenance can be conveniently handled by those with a minimum of training in electronics.

UP TWENTY PER CENT. Though not completely clarified, the Defense Department's budget for 1961 in terms of military electronics looks like it will hit $5.5 billion. This is an increase of some 20 per cent over the 1960 figure.

SUN NEVER SETS. True to the traditions of the Empire yesteryear, the British will soon find another means of linking the members of the Commonwealth. This time it will be an undersea cable network that can carry slow-scan TV as well as telephony. The first link, between Britain and Canada, is scheduled for completion in 1961. By 1964 the second leg, tying Canada to Australia, will be ready. And so on.

TERA, GIGA, NANO AND PICO. These are the four prefixes that the National Bureau of Standards has picked following recommendation of the International Committee on Weights and Measures. These four join the already-in-use: mega, kilo, hecto, deka, deci, centi, milli and micro. Tera is 10^{12}; giga, 10^{9}; nano, 10^{-9}; and pico, 10^{-12}. Symbols for these new prefixes are, respectively, T, G, n and p. For example, 10^{-12} farad is a picofarad and is written in abbreviated form thusly: 1 pf.

JURY-SIZED SUB? The Navy is deep into a program (along with nine private firms and research groups) to put into the brine a fully automated sub that will need a crew of only 12. Automated and integrated will be the five fundamental control areas, or "loops": ship control, communications, engineering, weapons and environmental.

CABLEMAN'S CORNER. The old adage "Don't put the cart before the horse" was never so true as it is in these days of automation and instrumentation. With all the intricate pieces of equipment being designed these days, it is important that careful consideration be given to the wire and cable that may be employed in any system. Often forgotten is the unromantic aspect of the connecting links of the system. Cables are the arteries through which must flow the power and informational pulses necessary for reliable performance.

Don't take a chance on being able to obtain a cable that will fit into what is left. Many times, important characteristics such as conductor size, insulating walls, protective sheaths, flexibility and flex-life have to be sacrificed. Don't sacrifice reliability in your cables for an existing space or connector fittings.

For 100% reliability in multi-conductor cables, call on a cable specialist—and call on him as soon as possible. Phone Rome 3000, or write: Rome Cable Division of Alcoa, Dept. 1240, Rome, New York.

These news items represent a digest of information found in many of the publications and periodicals of the electronics industry or related industries. They appear in brief here for easy and concentrated reading. Further information on each can be found in the original source material. Sources will be forwarded on request. ⑰

KLYSTRONS AND MAGNETRONS

EMI

E.M.I. klystrons and magnetrons are available in a wide range of types and specifications to meet your particular and exacting requirements ■ Through the Hoffman Electron Tube Corp. — U.S. representative for E.M.I. — these tubes can be promptly delivered from inventory. Rugged, reliable E.M.I. klystrons and cavities range from 0.5 to 46.0 KMC . . . Magnetrons are available as packaged types for pulse operation; in "E", "Q", and "J" bands; forced-air cooled; indirectly heated cathodes; millimeter operation ■ E.M.I. Electronics Ltd. is one of the world's leading pioneers in the development of special and standard high-performance tubes for military and commercial use.

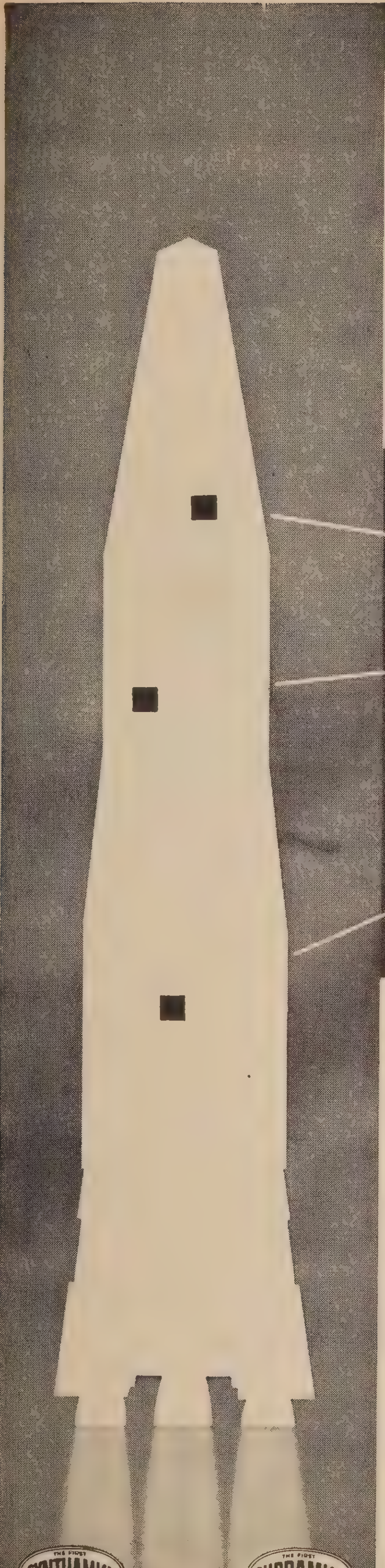
You can rely on E.M.I. for the highest standard of accuracy and reliability.

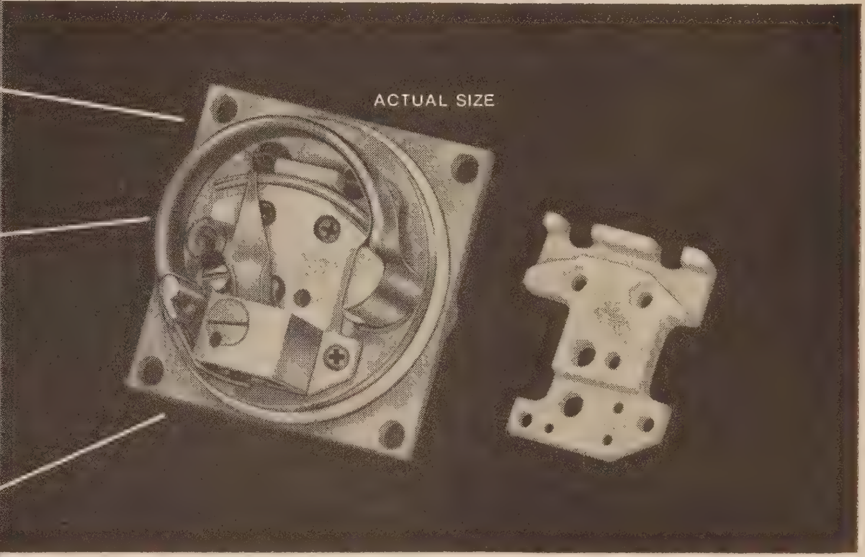
Send for your copy of the new E.M.I. 300-page catalog.

Hoffman Electron Tube Corp.
804 Newbridge Avenue
Westbury, New York

SUPRAMICA® 555 ceramoplastic

the world's most nearly perfect precision-moldable electronic insulation





for total reliability . . . at high temperatures . . . specified in BOURNS Inc. transducers

Why did Bourns, Inc. select SUPRAMICA 555 ceramoplastic as the insulating base for its ultra high-temperature differential pressure transducers?

Bourns' engineers cite three reasons . . . each a contribution to the total reliability of these airborne telemetering devices. "First is temperature. The sensitive element of the mechanism must withstand high operating temperatures. Next, SUPRAMICA 555 offers a combination of excellent insulating characteristics, which are essential to the highly accurate functioning of the potentiometer. In addition, this ceramoplastic material is readily moldable into complex shapes, such as that required for this intricate part."

For other applications SUPRAMICA 555 is used under operating conditions as high as +700°F. . . . SUPRAMICA 555 is one of the many ceramoplastic and glass-bonded mica insulation materials produced by Mycalex Corporation of America, in precision-molded and machinable formulations. Whatever your insulation need there is a Mycalex product to meet it—for example, SUPRAMICA 620 machinable ceramoplastic, which has a maximum operating temperature of +1550°F. Write today outlining your design problem for specific information.

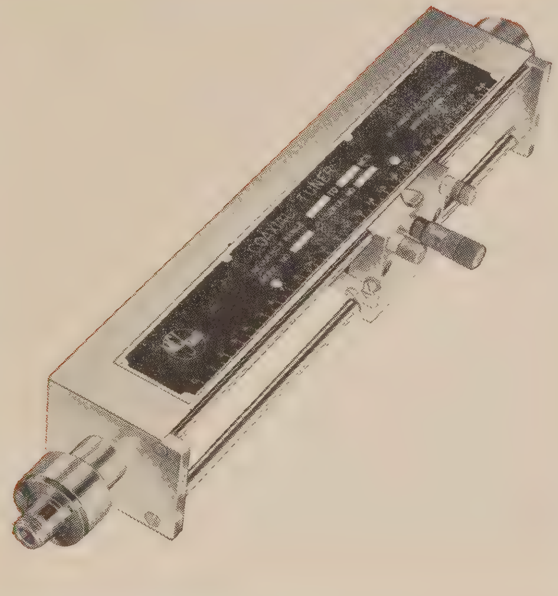
General Offices and Plant: 126 Clifton Blvd., Clifton, N. J.
Executive Offices: 30 Rockefeller Plaza, New York 20, N. Y.

THE FIRST SYNTHAMICA® SYNTHETIC MICA
SINCE 1919 MYCALEX®
THE FIRST SUPRAMICA® CERAMOPLASTIC

MYCALEX
CORPORATION OF AMERICA

WORLD'S LARGEST MANUFACTURER OF GLASS-BONDED MICA AND CERAMOPLASTIC PRODUCTS

PRECISE MicroMatch® COAXIAL TUNERS TUNE TO VSWR 1.000 200-4000 MCS.



MAKES YOUR LOAD A REFLECTIONLESS TERMINATION

DESIGNED FOR USE whenever extremely accurate RF power terminations are required. This laboratory type Coaxial Tuner will tune out discontinuities of 2 to 1 in coaxial transmission line systems or adjust residual VSWR to 1.000 of loads, antennas, etc. May also be used to introduce a mismatch into an otherwise matched system.

M. C. JONES COAXIAL TUNER is designed for extreme ease of operation, with no difficult laboratory techniques involved. Reduces tuning time to a matter of seconds. Graduations on carriage and probe permit resetting whenever reusing the same termination.

SPECIFICATIONS

Impedance	50.0 ohms
Frequency Range	Model 151N 200-1000 Mcs. Model 152N 500-4000 Mcs.
RF Connectors	E1A ⅞" 50.0 ohm Flange plus adapters to N female connector
Power Rating	100 watts
Range of Correction	VSWR as high as 2 may be reduced to a value of 1.000

FOR MORE INFORMATION ON TUNERS, DIRECTIONAL COUPLERS, R. F. LOADS, Etc., PLEASE WRITE TO:

M.C. Jones

M. C. JONES ELECTRONICS CO., INC.
185 N. MAIN STREET, BRISTOL, CONN.
SUBSIDIARY OF Bendix AVIATION CORPORATION

VOICE *via* LIGHT BEAM

In Space . . . On Earth . . .

New power sources and electronic controls now permit transmission of voice communications between line-of-sight points using a narrow, high intensity beam of light . . .

FOR

- **Military applications requiring maximum security**
- **Civilian applications requiring privacy and where wires are not available**
- **Use in hazardous locations where radio waves could cause explosions or interference**

Electron Arc's power supplies are designed for use with high intensity light source lamps such as the Sylvania concentrated arc lamps. Complete units are available from 2 to 300 watts with varying light source diameters from 0.005 to 0.110 inch—with average brightness of 15,000 to 30,000 candles per square inch.

When used with the appropriate concentrated arc lamps, the system provides a ready and highly efficient source of *infrared* energy. Such units are finding extensive applications in communication and detection systems.

EA's line of power supplies and accessories for high intensity light sources are ideal for use in:

- **Laboratory instruments**
- **Photographic equipment**
- **Projection systems**
- **Photomicroscopy**
- **Collimating systems**
- **Medical and surgical equipment**

Other EA products include transformers and power equipment for special applications with a wide range of frequencies, and voltages to 100 kw and higher. DC power sources with controlled outputs and special voltages include rectifiers for higher voltages and currents than normally available.

IONICS

ELECTRON ARC DIV.
IONICS, INCORPORATED
244 Broad Street • Lynn, Massachusetts

New LAMBDA
Regulated Power Supplies
5 and 10 AMP 0-32 VDC

CONVECTION COOLED

LAMBDA
REGULATED POWER SUPPLY
5-Year
Guarantee

GUARANTEED FOR 5 YEARS

- **Convection cooled—no internal blowers to wear out**
- **Ambient temperature 50°C**
- **Excess ambient thermal protection**
- **Fast transient response**
- **Special, high purity foil, hermetically sealed long-life electrolytic capacitors**
- **Hermetically sealed transformer designed to MIL-T-27A**
- **Remote sensing and DC vernier**

New LAMBDA LA Series Condensed Data

DC OUTPUT:

(Regulated for line and load)

MODEL	VOLTAGE RANGE[1]	CURRENT RANGE[2]	PRICE
LA50-03	0-32 VDC	0- 5A	$395
LA50-03M	0-32 VDC	0- 5A	$425
LA100-03	0-32 VDC	0-10A	$510
LA100-03M	0-32 VDC	0-10A	$540

[1] The output voltage for each model is completely covered in four steps by selector switches plus vernier control and is obtained by summation of voltage steps and continuously variable DC vernier as follows:

MODEL	VOLTAGE STEPS
LA 50-03, LA 50-03M	2, 4, 8, 16 and ±2 volt vernier
LA100-03, LA100-03M	2, 4, 8, 16 and ±2 volt vernier

[2] Current rating applies over entire output voltage range

Regulation: Line: Better than 0.15 per cent or 20 millivolts (whichever is greater). For input variations from 100-130 VAC. Load: Better than 0.15 per cent or 20 millivolts (whichever is greater).

Transient Response: Line or Load: Output voltage is constant within regulation specifications for step function line voltage change from 100-130 VAC or 130-100 VAC or for step-function load change from 0 to full load or full load to 0 within 100 microseconds after application.

Ripple and Noise: Less than 1 millivolt rms with either terminal grounded.

AC INPUT:

100-130 VAC, 60 ± 0.3 cycles[3]

[3] Well within standard commercial power line frequency tolerances in the United States and Canada.

OVERLOAD PROTECTION:

Electrical: Magnetic circuit breaker front panel mounted. Special transistor circuitry provides independent protection against transistor complement overload. Fuses provide internal failure protection. Unit cannot be injured by short circuit or overload.

REMOTE SENSING:

Provision is made for remote sensing to minimize effect of power output leads on DC regulation, output impedance and transient response.

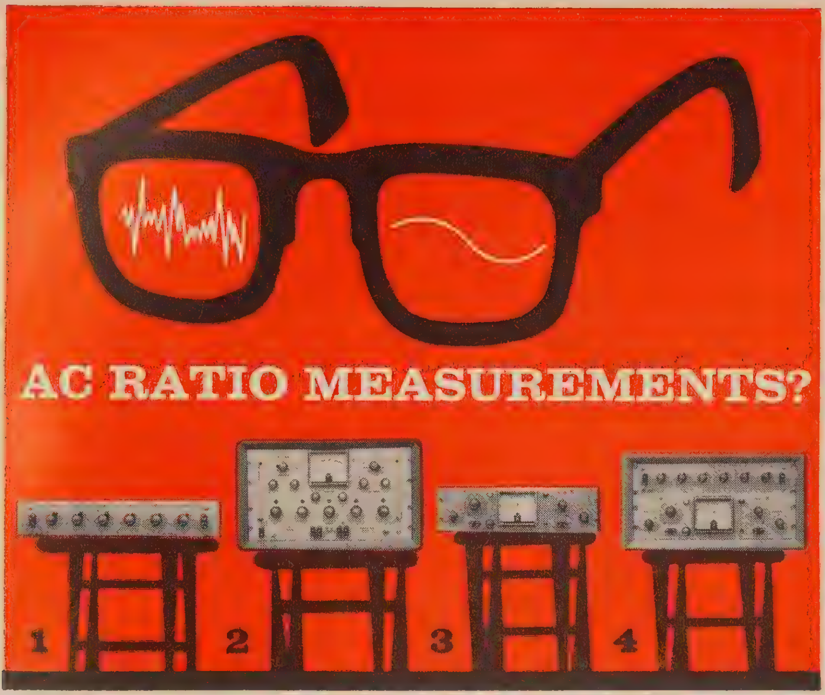
PHYSICAL DATA:

Size:
LA 50-03 . . . . 5¼″ H x 19″ W x 14⅜″ D
LA100-03 . . . . 7″ H x 19″ W x 14⅜″ D

Panel Finish: Black ripple enamel (standard). Special finishes available to customers specifications at moderate surcharge. Quotation upon request.

Send today for complete data

λ LAMBDA ELECTRONICS CORP.



THERE'S A NORTH ATLANTIC INSTRUMENT TO MEET YOUR REQUIREMENTS, TOO...

Now—from North Atlantic—you get the complete answer to AC ratio instrumentation problems—in the laboratory, on the production line, in the field.

Specialists in ratiometry, North Atlantic offers the only complete line of precision instruments to handle any ratio measurement task. All are designed to meet the most demanding requirements of missile age electronics—provide high accuracy, flexibility, component compatability and service-proven perforformance. Some are shown above.

If your project demands total solution to ratio measurement problems, write for Date File No. 10M It provides complete specifications and application data and shows how North Atlantic's unparalleled experience in ratiometry can help you.

1. RATIO BOXES:	2. COMPLEX VOLTAGE RATIOMETERS	3. PHASE ANGLE VOLTMETERS	4. RATIO TEST SETS
Both laboratory standards and general duty models. Ratio accuracies to 0.0001%. Operation from 25 cps to 10 kc.	Integrated, single-unit system for applications where phase relations are critical. Accuracy to 0.0001%, unaffected by quadrature. Three frequency operation. Direct reading of phase shift in milliradians or degrees.	Versatile readout system for all ratiometry applications, providing direct reading of phase, null, quadrature, in-phase and total voltage. Broadband, single-, or multiple-frequency operation.	Ratio reference and readout in one convenient package for production line and similar applications. Can be supplied with any desired combination of ratio box and phase angle voltmeter.

NORTH ATLANTIC INDUSTRIES, INC.
603 MAIN STREET, WESTBURY, N.Y. • EDGEWOOD 4-1122

TUBE PROBLEM:

The Armed Forces needed a new version of the 6J4 reliable tube type which would provide a tube life of almost 1000 hours. Existing tubes of this type had an average life of only 250 hours. In addition, this new tube had to be produced under ultra-high quality control standards.

SONOTONE SOLVES IT:

By making improvements in the cathode alloy and setting up extremely tight controls in precision, manufacture and checking, Sonotone engineers produced a 6J4WA with a *minimum* life of 1000 hours... most running *much longer.*

RESULTS:

The Sonotone 6J4WA is one of three reliable tubes now being manufactured under U.S. Army Signal Corps RIQAP (Reduced Inspection Quality Assurance Program), monitored by the U.S. Army Signal Supply Agency. And the same rigid quality standards apply to Sonotone's entertainment type tubes as well.

Let Sonotone help solve *your* tube problems, too.

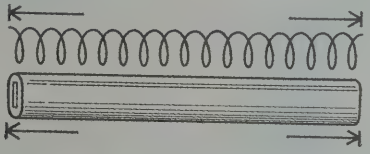
Sonotone® CORP.
Electronic Applications Division, Dept. T42-40
ELMSFORD, NEW YORK
Leading makers of fine ceramic cartridges, speakers, microphones, tape heads, electron tubes.
In Canada, contact Atlas Radio Corp., Ltd., Toronto

BOURNS TRIMPOT® WITH BUILT-IN TEMPERATURE STABILITY

Stable settings under extreme temperature conditions is an outstanding feature of the Trimpot® potentiometer. This thermal stability is built-in through all phases of design and production—

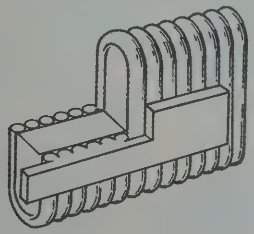
MATCHED COEFFICIENTS OF THERMAL EXPANSION

Resistance wire and mandrels have matched coefficients of thermal expansion to reduce the "strain gage effect." Linear expansion rates for the mandrel and wire match so closely that the temperature coefficient value for the entire wirewound element approximates that of the wire itself.



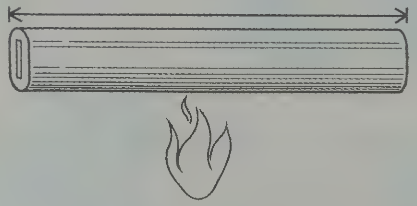
EXCLUSIVE SILVERWELD® TERMINATION

Silverweld is an actual metal-to-metal fusion of element wire and external terminal. In doing away with mechanical or soft-solder joints, Bourns eliminates potential hot spots thus extending the potentiometer's temperature range. The fusion of the Silverweld terminal to many turns of wire on the resistance element avoids the problem of single wire termination. Silverweld is virtually indestructible under thermal stresses.



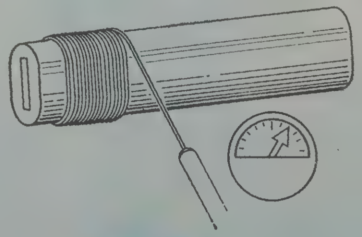
THERMALLY STABLE CERAMIC MANDRELS

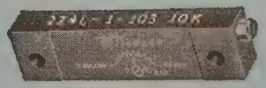
Bourns takes advantage of high thermal stability of ceramic materials for element mandrels. Today, all Bourns Trimpot potentiometers provide the improved performance and reliability afforded by ceramic materials.



EXCLUSIVE TENSION CONTROL EQUIPMENT

Bourns has developed specialized winding equipment that provides constant and precise control of wire tension during winding operations. "Necking" of the wire or resistance-altering stresses never occur. Instead the wire remains uniform—well able to withstand temperature variations with no appreciable change in resistance.





Specify Trimpot—the original leadscrew-actuated potentiometer with reliability on which you can depend. 20 basic models—4 terminal types—3 mounting styles.

BOURNS

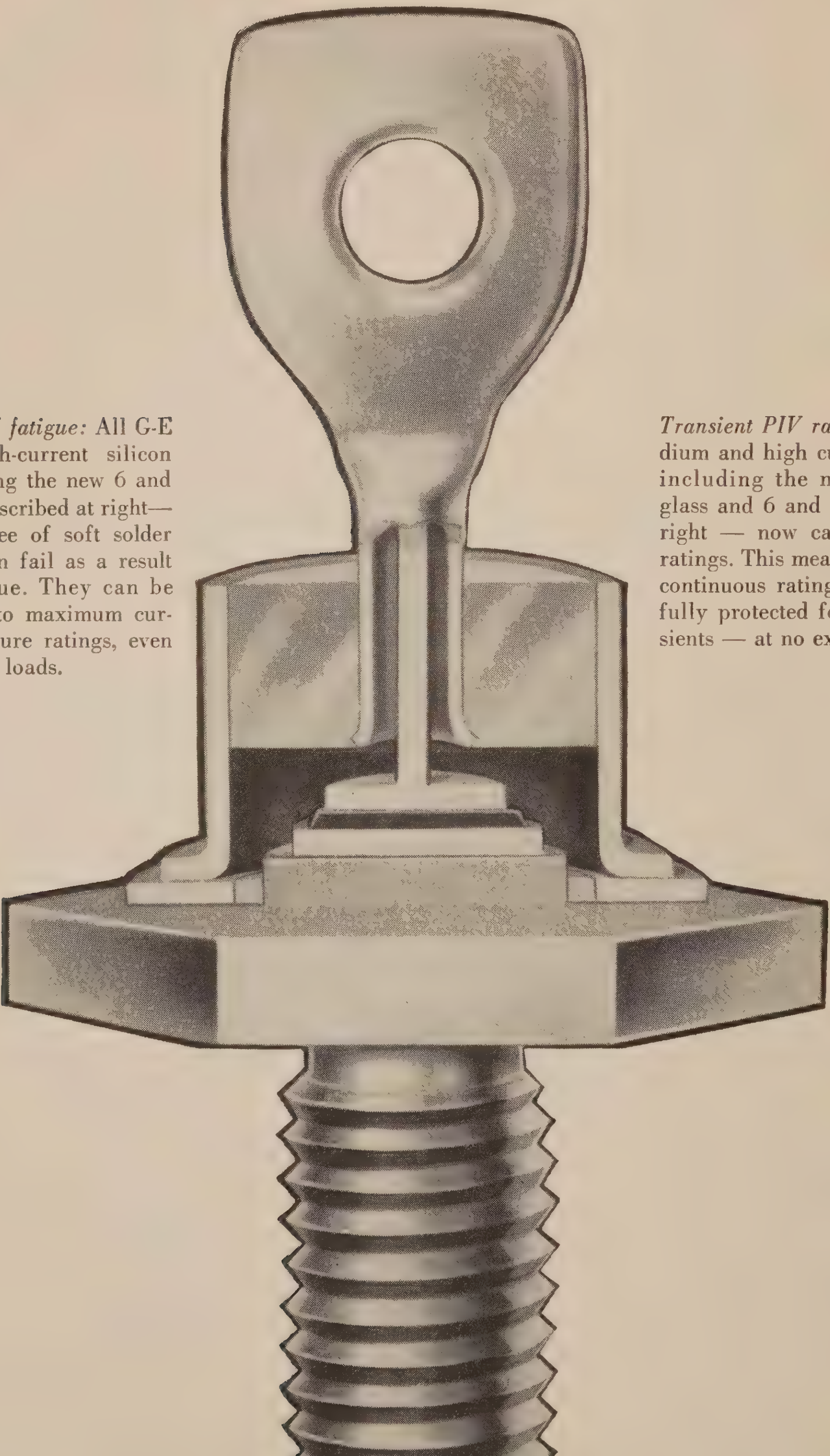
BOURNS, INC., TRIMPOT DIVISION
6135 MAGNOLIA AVE., RIVERSIDE, CALIF.
PLANTS: RIVERSIDE, CALIF. AND AMES, IOWA

Write for new Trimpot summary brochure and list of stocking distributors.

Exclusive manufacturers of Trimpot®, Trimit® and E-Z-Trim®. Pioneers in transducers for position, pressure and acceleration.

NEW RECTIFIERS FROM

Free from thermal fatigue: All G-E medium and high-current silicon rectifiers—including the new 6 and 12-amp. devices described at right—are completely free of soft solder joints, which often fail as a result of thermal fatigue. They can be worked right up to maximum current and temperature ratings, even on highly cyclical loads.



Transient PIV ratings. All G-E medium and high current rectifiers — including the new subminiature glass and 6 and 12-amp. devices at right — now carry *transient* PIV ratings. This means you can buy the continuous rating you need and be fully protected for occasional transients — at no extra cost!

GENERAL ELECTRIC

New Silicon Subminiature Glass Rectifier

Designed for maximum thermal conductance over a wide temperature range. Suitable for MIL-E-1/1143. Extremely low leakage currents. Ideal for magnetic amplifier, blocking and other low-leakage applications.

JEDEC or GE Type Number	Repetitive PIV	Transient PIV	Max. I_{DC} at T°C	Max. Lkge Cur. (Full cycle Av.)	Max. Full Load Voltage Drop (Full cycle Av.)	Max. Oper. Temp.
			@ 150°C	@ 100°C	@ 25°C	
1N645	225	275	150 ma	15 μa	IV	175°
1N646	300	360	150 ma	15 μa	IV	175°
1N647	400	480	150 ma	20 μa	IV	175°
1N648	500	600	150 ma	20 μa	IV	175°
1N649	600	720	150 ma	25 μa	IV	175°
				@ 150°C		
1N677	100	20	400 ma	.2 ma	IV	175°

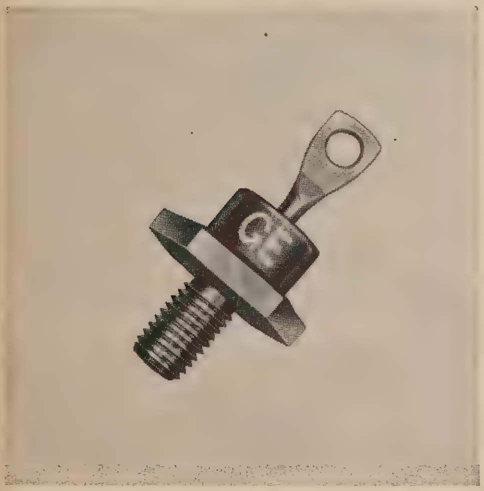
1N676-1N679, 1N681-1N687 and 1N689 also available in this package.

New Silicon Insulated Stud Mounted Junction Rectifier

Designed for applications requiring fins or direct chassis mounting. Stud electrically insulated from rectifying junction. High forward currents permitted at case temperatures up to 150°C (up to 165°C with derating). Reverse current at maximum junction temperature extremely low, making these devices ideal for low-leakage applications.

JEDEC or GE Type Number	PIV	Max. I_{DC} at T°C	Max. Peak 1 cycle Surge	Max. Lkge Cur. (Full Cycle Av.)	Max. Full Load Voltage Drop (Full Cycle Av.)	Max. Oper. Temp.
		@ 50°C Case		@ 150°C	@ 150°C	
1N2851	500	1.5 Amps	15 Amps	.3 ma	.65V	150°
1N2852	600	1.5 Amps	15 Amps	.3 ma	.65V	150°
		@ 75°C Case				
1N2847	100	1.5 Amps	15 Amps	.4 ma	.65V	165°
1N2848	200	1.5 Amps	15 Amps	.3 ma	.65V	165°
1N2849	300	1.5 Amps	15 Amps	.3 ma	.65V	165°
1N2850	400	1.5 Amps	15 Amps	.3 ma	.65V	165°

New Silicon Medium Current 6 and 12-amp. Junction Rectifiers



With these new devices, General Electric now offers the widest selection of rectifiers in the medium current range. Designed for all rectifier applications from 2 to 15 amperes. Extremely low forward voltage drop and thermal impedance combined with high junction temperature rating permit high current operation with minimum space requirements. May be mounted directly to chassis or fin or electrically insulated from heat sink by using mica washer kit provided with each unit.

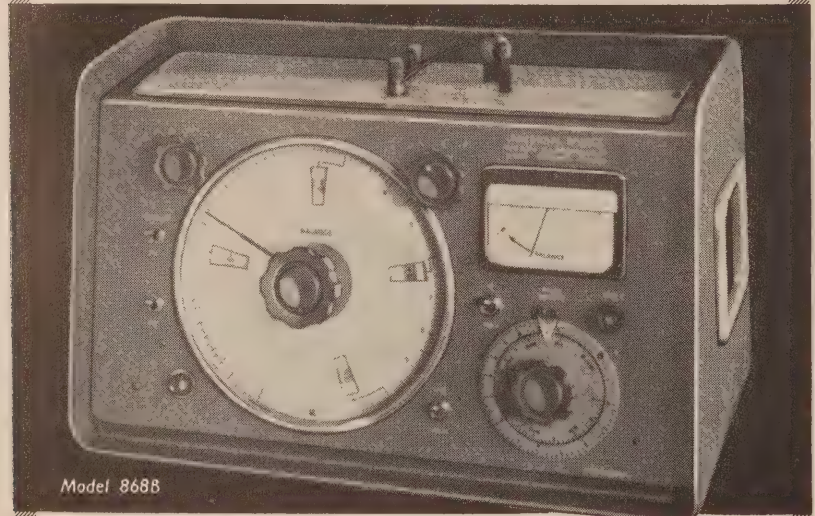
JEDEC or GE Type Number	Repetitive PIV	Transient PIV	Max. I_{DC} @ 145°C Stud Single Phase	Max. Peak 1 Cycle Surge	Max. Lkge Cur. (Full cycle Av. @ Full Load)	Max. Full Load Voltage Drop (Full Cycle Av.)	Max. Oper. Temp. °C
					@ 150°C Stud	@ 150°C Stud	
1N1341A	50	100	6A	150A	3 ma	.64V	200°
1N1342A	100	200	6A	150A	2.5 ma	.64V	200°
1N1343A	150	300	6A	150A	2.25 ma	.64V	200°
1N1344A	200	350	6A	150A	2.0 ma	.64V	200°
1N1345A	300	450	6A	150A	1.75 ma	.64V	200°
1N1346A	400	600	6A	150A	1.5 ma	.64V	200°
1N1347A	500	700	6A	150A	1.25 ma	.64V	200°
1N1348A	600	800	6A	150A	1.0 ma	.64V	200°
1N1199A	50	100	12A	240A	3 ma	.55V	200°
1N1200A	100	200	12A	240A	2.5 ma	.55V	200°
1N1201A	150	300	12A	240A	2.25 ma	.55V	200°
1N1202A	200	350	12A	240A	2.0 ma	.55V	200°
1N1203A	300	450	12A	240A	1.75 ma	.55V	200°
1N1204A	400	600	12A	240A	1.5 ma	.55V	200°
1N1205A	500	700	12A	240A	1.25 ma	.55V	200°
1N1206A	600	800	12A	240A	1.0 ma	.55V	200°

For more information, see your General Electric Sales Representative, or write Semiconductor Products Dept., Electronics Park, Syracuse, N. Y. In Canada: Canadian General Electric Co., 189 Dufferin St., Toronto, Ont. Export: International General Electric Co., 150 E. 42 St., N.Y.C. See your authorized General Electric Distributor for fast service, factory-low prices.

GENERAL ELECTRIC

THE NEW MARCONI UNIVERSAL BRIDGE

Gives NEW Simplicity in LCR Measurements



L — 1 μH to 100 henrys
C — 1 μμF to 100 μF
R — 0·1 ohm to 100 MΩ

•Direct read-out with no multiplying factors, eliminates operator errors. •Model 868 B also has precision Q and tan δ (D) dials. Inductance and capacitance are measured at 1 or 10 kc/s in an R-C ratio-arm bridge; resistance at d.c. in a Wheatstone bridge. The bridge detector gives positive indication of the direction of balance point even when far off-balance; as a result, components whose values are completely unknown can be evaluated in a few seconds with the minimum of searching. Detector a.g.c. eliminates the need for sensitivity controls.
Also available—**Low Capacitance Bridge Model 1342:** 0·002μμ F to 1,111μμ F; 3-terminal transformer ratio-arm bridge designed for precision measurement of extremely low capacitance.
For full details, write for leaflet D171.

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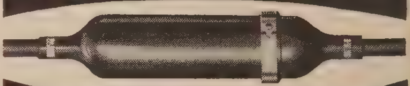

- designed for fast, convenient splicing, saving hours of time and labor.
- provide *permanent* moisture and dust-proof seal.

CONNECTOR CASES—maximum protection for connectors used in field equipment.

- fit any size or type of connector.
- stepped ends can be cut to size of wire or cable being used.

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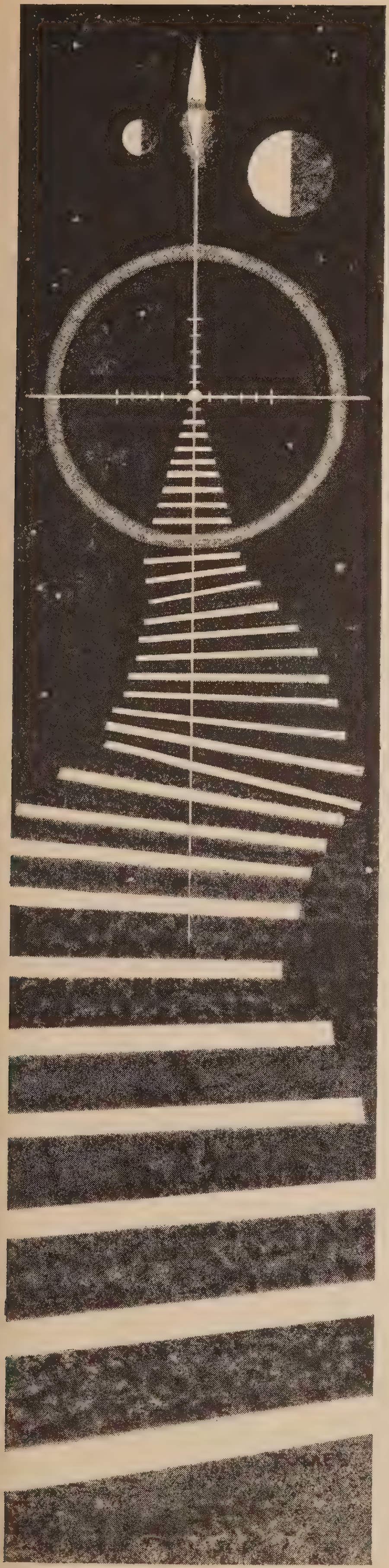

Horizons Unlimited

Development of a high-performance inertial guidance system of unprecedented performance for long-range guided missiles, satellites and space vehicles has been announced by Bell Aircraft Corporation's Avionics Division.

Bell Avionic's engineers describe the highly-classified system as "the most successful and reliable of any new inertial instrumentation concepts so far tested."

The system was developed under the direction of Dr. Helmut W. Schlitt, recognized within the industry as an outstanding authority in the field of inertial guidance.

The new system has undergone extensive flight tests at the Niagara Falls, N.Y., Municipal Airport. Some of its components already are being used in guided missiles.

Bell Aircraft's Avionics Division also is engaged in many other important programs, including Battlefield Monitoring Systems, All-Weather Automatic Aircraft Landing Systems and Secure Data Link Systems.

The Avionics Division recently has joined with Pan-American World Airways, Inc. to find a solution to the serious problem of radio interference with the operation of Army combat electronic equipment.

Bell and Pan-Am's Guided Missiles Range Division will set up an electronic environmental test facility and drone test range near Fort Huachuca, Ariz., to track down the source of the interference, submit recommendations for corrective action and initiate procedures to eliminate these conditions.

Experienced engineers and scientists are needed for all of these programs. For information, write George Klock, director of engineering employment, today.

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F-28/APN-19 FILTER CAVITY
Jan. spec: Tuneable 2700-2900mc, 1.5db max. loss at ctr freq over band. Details: Insertion loss variable. Single tuned filter for freq channelling in radar beacon. Invar center tuning conductor ¾ wavelength. New $37.50 each.

2C40 LIGHTHOUSE CAVITY
AN/APW-11A transmitter cavity for 2C40. Complete S band coverage at max. power. Temperature compensated. New $77.50 ea.

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Complete RF head including transmitter, receiver, modulator. Uses 2J42 magnetron. Fully described in MIT Rad. Lab. Series Vol. I, pps. 616-625 and Vol. II, pps. 171-185. $375.00. Complete X band radar system also avail. incl. 360 deg. antenna, PPI, sync, pwr supply. Similar to $17,000 weather radar now in use by airlines $750 complete.

10 CM. WEATHER RADAR SYSTEM
US Navy Raytheon 275 KW peak output S band. Rotating yoke Plan position Indicator. Magnetron supplied for any S band frequency specified, incl. Weather Band. 4, 20 and 80 mile range. 360 degree azimuth scan. Sensitive rcvr using 2K28/707B and 1N21B. Supplied brand new complete with instruction books and installation drawings. Can be supplied to operate from 32VDC or 115 volts. Price $975. Ideal for weather work. Has picked up clouds at 50 miles. Weight 488 lbs.

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TS 731/URM. Portable, general purpose, field type, ruggedized wattmeter used to measure R.F. power output of radio, radar & navigation equips. A direct reading summation type circuit in which a bolometer acts as one arm of a D.C. Weatstone bridge, at the same time providing correct resistivity termination for R.F. entering the wattmeter. Power supply: 115-VAC, 1 ph.50-1600 cy. Freq. range: 1000 to 4000 mcs with plumbing supplied. VSWR less than 1.3 Gov't cost well over $1000 in large quantity. Your cost—$395 ea. Factory new.

AN/APN-60
10 CM. RADAR BEACON FOR GUIDED MISSILES. 14″ pressurized housing. 2C40 lighthouse OSC. Trans-revr. unit $275.00.

⅞″ RIGID COAX. RG44/U 50 ohm, standard fittings. 10cm stub supported. 12 ft. lengths. Silver plated. New $34.50 each. 12 ft. length. Right angle bends $6 ea.

X BAND HORN. Waveguide feed pressurized window. 180 Deg. feed back. New $22.50.

TOPWALL HYBRID JUNCTION. 8500-9600mc 1x.5 wg size. Broad banded better than 16%. Aluminum casting. $15.00 new. Crossover output. 1x.5 wg size. $5.00 new.
BROAD BAND BAL MIXER using short slot-hybrid. Pound type broad band dual balanced crystal holder. 1x.5 wg size. $25.00 new.

FLEXIBLE WAVEGUIDE. 1x.5 X band 4″, new $5.00. 1x.5 X band 9″ Technicraft. New $10.00. 1.5 X band 24″ Airtron. New $21.50. 1¼″ x ⅝″ X band 12″ Western Elec. New $19.50.
RG48 TO ⅞ COAX. ADAPTER S Band 1½ x 3″ W.G. to RG 44/U coax. New. $26.50.
COAX MIXER ASSEMBLY S BAND IN21 type crystal detector RF to IF, 'N' fittings, matching Slug, duplex couplings, mf. G.E. New, $18.50.

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Ground control approach equipped trailer with 3 cm precision and 10 cm search radars plus full complement precision and search indicators. All in original trailer. Call—write for info. and price. Fully Desc. MIT Rad. Lab. Series, Vol. II, pps. 237-251.

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MIT Model 9 PULSER
1 MEGAWATT-HARD TUBE
Output pulse power 25KV at 40 amp. Max duty ratio: .002. Uses 6C21 pulse tube. Pulse duration .25 to 2 microsec. Input 115 volts 60 cycle AC. Includes power supply in separate cabinet and driver. Fully guaranteed as new condition. Full Desc. MIT. Rad. Lab. series "Pulse Generators."

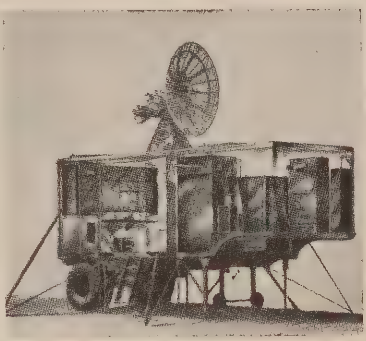
24KMC. PKG. MAGNETRON
3J21 Magnetron. 60kw output at 1.25cm, K band. 15kv 15 amp. input. Axial cathode mount. Waveguide output. Packaged with magnet. New $87.50 ea. gtd.

SPERRY KLYSTRONS
SMX-32 Amplifier-Multiplier 9.0-10.5-KMC. Amp. freq. multiplier; output power 1.5 to 2 watts at 9000 to 10,500 mc; drive freq. 4500 to 5250 mc. New in original sealed cartons. Guaranteed 90 days. Regular price $925 ea. Our price $425 ea.
SMC-11A Frequency multiplier. Output range 4640-4670 mc. ½ to 1 watt on 6th harmonic. Input range 773-778 mc. For direct control of microwave frequencies. New in original sealed cartons. Guaranteed 90 days. Regular price $1500 ea. Our price $495 ea.

2 MEGAWATT PULSER
Includes Rectifier xfmr 5800/7000V, 2.2/2.55-KVA; Resonant charging choke 150 cy. 30H 12 Amp. Ins. 17KV; Capacitor network 17E2-2-300-25P2T; Capacitor .04Mfd. 17KVDC; Transformer 4400V to 22,000V; Fil. Xfmr. & Filter choke 5.1V 18Amp, 6 H .21Amp. DC; 4C35 pulser, 3B24W (6 each), WL1B41 gap tube. Price new type MD-53/APS20C $1125.00

AN/SPT-6A TRANSMITTER
350 to 1400mc countermeasures jammer. 115V 60 cy AC input. New and complete operating unit. $750.00

FM 3CM. SIGNAL GENERATOR
TS-263/TPS-10 X band FM signal generator. Tunes 9KMC band. With calib. atten. Regulated pwr supply. New $325.00
TAPER. RG51 to RG52 (1¼ x ⅝″ to 1 x ½″) Smooth Electroform. Standard Flankes. New $16.50.



SCR 584 ANTENNA SYSTEM

Full azimuth and elevation sweeps. 360 degrees in azimuth. 210 degrees in elevation. Accurate to 1 mil. over system. Complete for full tracking response. Includes pedestal drives, selsyns, po-Excellent used condition. This is the first time tentiometers, drive motors, control amplidynes. Excellent used condition. This is the first time these pedestals have been available for purchase. Limited quantity in stock for immediate shipment. Ideal for antenna pattern ranges, radar systems, radio astronomy, any project requiring accurate response in elevation and azimuth. Compl. operations console all housed in trailer.
Complete description in McGraw-Hill Radiation Laboratory Series, Volume I, page 284 and page 209, and Volume 26, page 233.

RT39/APG-5 & 15 10CM RADAR. Complete S band RF package. Lighthouse 2C40 xmtr. 2C43 rcvr, TR. 829B pulser, miniature 6AK5 IF strip. Press. 12″ dia., 24″ lg. New with tubes $275. Ref: MIT Rad. Lab. Series Vol. I, pg. 207.

74 to 320 MC BUTTERFLY TUNER
Rotates thru 360 deg. either hand or motor driveable. New, $22.50 ea.

VG-12″ PROJECTION PPI RRTR $395.00.
CPS-1, PPI 12″. NEW, $275.00.

TS-743/U SIGNAL GENERATOR
15,250 to 16,250mcs, calibrated attenuator, 115VAC regulated power supply. Mfg. Polarad. Exc. condition $1250. each.

KLYSTRON MOUNTS
3CM. Precision Tube Mount. Waveline model 688. X band shielded klystron mount PRD signal generator type. Complete with variable glass vane attenuator. Brand new. $205. list. Price $45.00.
S. band. Type N output. Tunable over entire band. For Shepard type tube i.e. 726 w/socket & tube clamp. Mfg. GE. New, $15.00.
K band. 2K50 output cplg. w/90 deg. H bend. New. $19.50.

NEWS New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

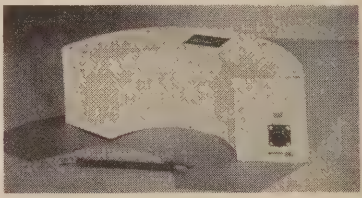
(Continued from page 183A)

any machine requiring two- or three-axis positioning, such as drilling, boring, turning equipment, punch presses, spot welders, and eyelet inserters for circuit board sub-assemblies.

Copies of the brochure may be obtained by writing to the firm.

"Shaped" Battery With Dual Voltage

A special, "shaped" electric APU power source containing two separate battery sections developed by **Cook Co.,** a subsidiary of **Telecomputing Corp.,** 3850 Olive St., Denver 7, Colorado, provides dual output for missile and spacecraft power requirements. The two battery sections in the Model P68A provide two different voltage levels.



One section provides a current of 8 amperes at 28 volts. Maximum current is 25 amperes, with a discharge time of 40 minutes at 8 amperes. Capacity is 5.5 ampere-hours.

The second section supplies 6.3-volt power at 3 amperes. Discharge time is 40 minutes. Maximum current is 25 amperes. Capacity is 5.5 ampere-hours.

Both sections are activated automatically. The activating mechanism is an electrolyte tank and piston arrangement, operated by a solid propellant gas generator. Activation time is 1 second. The signal required is 2 amperes at 28 volts.

The cells are specially designed for automatic activation and have foil anodes enclosed in sealed separators. This technique eliminates the problems of anode gassing and internal shorts. The entire unit is hermetically sealed to prevent leakage or contamination. The battery weighs 13 pounds.

The Model P68A will withstand shock to 50 g, acceleration to 20 g and vibration to 10 g, along all three major axes. Temperature range is from 50°F to 150°F, with special models providing ranges of −65°F to +165°F. Thermostatically controlled heaters are available.

Case material is steel. Mounting configuration is supplied to customer specifications. Standard or special connectors and terminals may be specified.

A fail-safe detection circuit may be provided for protection against premature activation. A double estimated activation ignition circuit overcomes shorts or open circuit failures. The estimated shelf life is 5 years.

(Continued on page 196A)

How to determine high-frequency characteristics of precision film resistors

Specify with confidence from this complete line of time-proved TI resistors

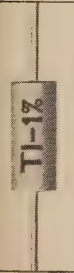
MOLDED†

TI type number	wattage rating watts	MIL designation	standard resistance ranges	max. recommended voltage volts
CDM⅛	⅛	RN60B	10 Ohm-1 Meg	350
CDM¼	¼	RN65B	10 Ohm-1 Meg	500
CDM½	½	RN70B	10 Ohm-5 Meg	750
CDM 1	1	RN75B	10 Ohm-10 Meg	1000
CDM 2	2	RN80B	50 Ohm-50 Meg	2000

MIL-LINE †

TI type number	wattage rating watts	MIL designation	standard resistance ranges	max. recommended voltage volts
CD⅛R	⅛	—	10 Ohm-1 Meg	350
CD¼R	¼	RN10X	10 Ohm-1 Meg	500
CD½PR	½	RN15X	10 Ohm-3 Meg	650
CD½MR	½	RN20X	10 Ohm-5 Meg	750
CD½SR	½	—	50 Ohm-10 Meg	850
CD1R	1	RN25X	10 Ohm-10 Meg	1000
CD2R	2	RN30X	50 Ohm-50 Meg	2000

HERMETICALLY SEALED LINE †



TI type number	wattage rating watts	MIL designation	standard resistance ranges	max. recommended voltage volts
CDH⅛M	⅛	—	10 Ohm-500K	250
CDH⅛	⅛	RN60B	10 Ohm-1 Meg	350
CDH¼	¼	RN65B	10 Ohm-1 Meg	500
CDH½P	½	—	10 Ohm-3 Meg	650
CDH½A	½	RN65B	10 Ohm-3 Meg	650
CDH½M	½	RN70B	10 Ohm-5 Meg	750
CDH½S	½	—	50 Ohm-10 Meg	850
CDH 1	1	RN75B	10 Ohm-10 Meg	1000
CDH 2	2	RN80B	50 Ohm-50 Meg	2000

†All values available in 1% tolerance; nominal lead length 1.5 in.

sensistor* SILICON RESISTORS

Standard available resistances @ 25° C:
68, 82, 100, 120, 150, 180, 220, 270, 330, 390, 470, 500, 560, 680, 820, 1000, 1200, 1500, 1800 ohms.‡

Type No.	Wattage Rating	Body Dimensions		Average Temperature Coefficient	Resistance Tolerance
	W	Length	Diameter	%/°C	%
TM ¼	¼	0.585″	0.200″	+0.7	±10
TM ⅛	⅛	0.406″	0.140″	+0.7	±10
TC⅛	⅛	TO—5	Transistor	+0.7	±10

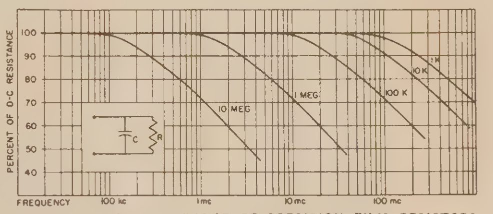
* TRADEMARK OF TEXAS INSTRUMENTS INCORPORATED
‡ Other resistance values and tolerances available on special order

For a more detailed discussion of this subject, contact your nearest TI sales office for a copy of "High-Frequency Characteristics of Precision Film Resistors."

In high frequency applications, precision film resistors are superior to composition or wirewound resistors; skin effect of the thin film is negligible.

OHMIC VALUE vs FREQUENCY

Precision film resistors of a given physical size have the same distributed capacitances regardless of their ohmic value. As the frequency increases, the shunting effect of the distributed capacitance causes the effective parallel resistance to decrease. The reactance of the stray capacitance becomes a relatively good shunt when it approximates the ohmic value of the resistor. The smaller the ohmic value of a precision film resistor (for a given physical size), the higher its usable frequency range.



HIGH FREQUENCY RESISTANCE OF PRECISION FILM RESISTORS

INDUCTANCE CONSIDERATIONS

The inductance caused by helixing the higher value resistors is negligible throughout the "useful" range of frequencies at which the resistance is greater than 60% of its d-c value.

When resistors under 500 ohms are measured using high frequency meters, the reactive component of the equivalent parallel circuit appears inductive because of lead and binding post inductance. However, the resistor itself is capacitive.

TI TYPE	SIZE (WATT RATING)				
	⅛	¼	½	1	2
MIL-LINE (CD)	0.2	0.1	0.25	0.5	0.6
MOLDED (CDM)	0.3	0.25	0.45	0.7	0.7
HERMETICALLY SEALED (CDH)	0.3	0.25	0.45	0.75	0.8

CAPACITANCE IN μμf OF TI PRECISION FILM RESISTORS

CAPACITANCE CONSIDERATIONS

The average measured capacitance of Texas Instruments Precision Film Resistors is determined primarily by the end cap-to-cap capacitance which is proportional to the dielectric constant of the core and encapsulating material.

MOUNTING

Precision film resistors of 200 ohms or less perform satisfactorily at 5000 mc and higher if placed in a well-designed coaxial mount. A coaxial mount constructed from a standard UG-18B/U Type N plug can be used effectively. In conventional terminals, correct mounting of the body of the resistor off the circuit chassis and the use of short leads will minimize the stray capacitance and lead inductance.

Specify TI precision resistors!

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(Continued from page 194A)

Correction Notice

Delay Lines

By using a new principle in delay network design, a new series of delay lines with ratio of rise time to total delay less than 0.02 has been achieved by **Ad-Yu Electronics Lab., Inc.**, 249–259 Terhune Ave., Passaic, N. J. Besides the feature of producing very fast rise time, the attenuation can be minimized to be less than 0.02 db per 1/10-microsecond delay. Two or more units of Type 10T series can be connected in tandem for longer delay whenever their impedances are identical. In this case, the time delay will be equal to the sum of the delay of each unit and the rise time will be approximately equal to the square root of the sum of the squares of the rise time of each unit.

The features of this delay line series can be summarized as follows: (1) The ratio of rise time total delay can be made less than 0.02. (2) The distortion is generally less than 2%. (3) The attenuation can be made less than 0.2 db per microsecond delay. (4) Physical size can be made less than 2 cubic inches per microsecond delay. (5) The temperature coefficient is less than 50 parts per million per degree Centigrade. (6) All types of this series can also be made to meet existent MIL specifications. The characteristic impedance ranges from 50 ohms to 1000 ohms. The time delay per 10 sections ranges from 0.25 microsecond to 5 microseconds. The accuracy of delay is less than ±1.5%.

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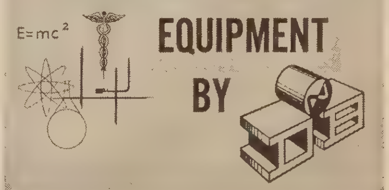

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3	7.60	15.40	17.10	20.80						
6	9.75	27.00	30.00	40.00						
10	19.90	33.60	38.45	46.75						
24	22.00	27.75	33.45	47.15						
50	32.00	55.75	60.45	88.90						
100	84.15	110.30	130.60	174.75						
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4	3.65	7.35	11.40	16.00	24.85	28.50	47.60	4.70
6	4.40	8.75	12.75	18.75	32.60	36.00	63.45	7.60
12	8.00	15.75	21.95	30.95	45.00	52.50	103.60	9.45
20	12.90	25.30	37.45	49.90	78.75	90.00	169.00	12.75
24	16.00	32.00	44.60	57.50	85.00	96.50	188.75	24.90
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18	2.25	2.90	3.45	3.85
35	2.75	3.25	3.90	4.45
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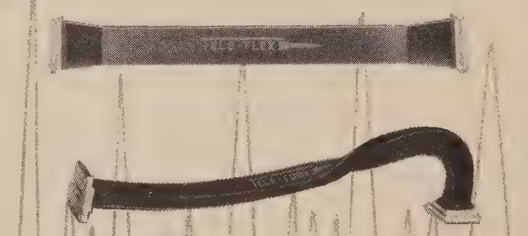

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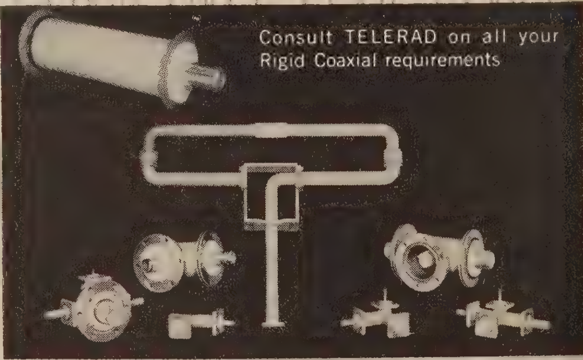

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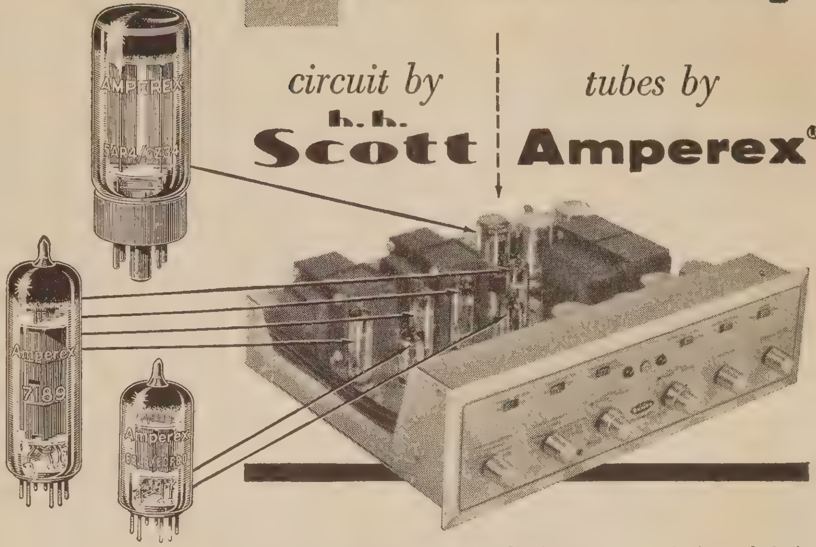

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12AX7/ECC83:
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6ER5: Frame grid shielded triode
6EH7/EF183: Frame grid pentode for IF, remote cut-off
6EJ7/EF184: Frame grid pentode for IF, sharp cut-off
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6DC8/EBF89: Duo-diode pentode

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6CA4/EZ81: Indirectly heated, 150 mA
5AR4/GZ34: Indirectly heated, 250 mA

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6FG6/EM84: Bar pattern
IM3/DM70: Subminiature "exclamation" pattern

SEMICONDUCTORS
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2N1516: RF transistor, 70 mc
2N1515: RF transistor, 70 mc
IN542: Matched pair discriminator diodes
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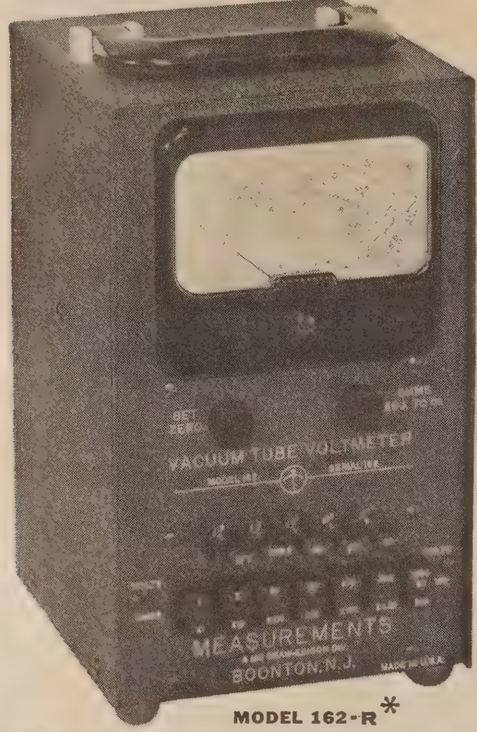

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*Ohms range 0.2 ohms to 500 megohms in 7 decades with 10; 100; 1,000; 10,000; 100,000 ohms, 1 megohm and 10 megohms mid-scale rating.

Price: $210.00 F.O.B. Boonton

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MEASUREMENTS
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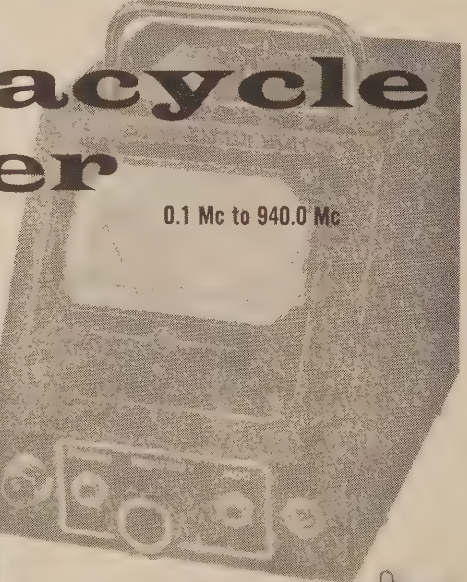
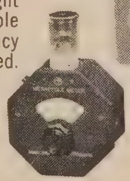
Megacycle Meter



0.1 Mc to 940.0 Mc

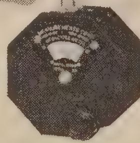
Determines resonant frequency of tuned circuits, antennas, transmission lines, by-pass condensers, chokes, etc. Measures inductance and capacitance. Also used as a signal generator, wave meter, frequency meter, and in many other applications.

This compact, lightweight grid-dip meter is available in the frequency ranges indicated.



Model 59 Oscillator
2.2 Mc - 420 Mc

Model 59-LF Oscillator
100 Kc - 4.5 Mc



Model 59-UHF Oscillator
420 Mc - 940 Mc

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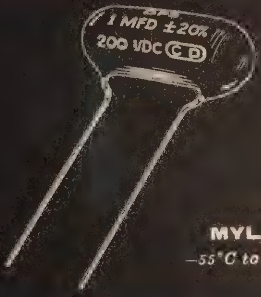
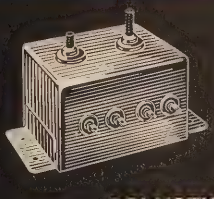
CDE *Consistently Dependable Capacitors*

TWTN1F502M
.005 MFD 600 VDC
250°C

TEFLON
−55°C to +250°C



MYLAR
−55°C to +160°C



POLYSTYRENE
−55°C to +85°C

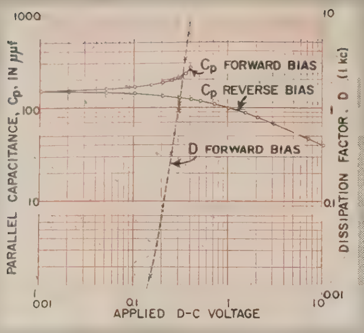
Cornell-Dubilier film dielectric capacitors... reliable for temperatures up to 250° C (under proper operating conditions)

Turn up the thermostat! Cornell-Dubilier's Teflon* film dielectric capacitors can take the heat...up to operating temperatures of 250°C without a moment's discomfort. For that matter, C-D's Mylar* and polystyrene are almost equally immune to any environmental, life or performance ordeal to which you may want to put them. C-D film dielectrics also offer the widest selection of electrical ratings, case styles, materials and configurations to satisfy space, weight and cost limitations. And they are immediately available in production quantities.

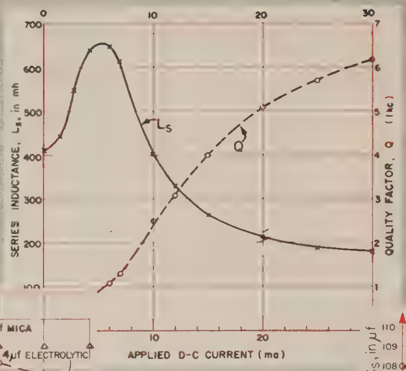
Ask now for C-D engineering assistance and bulletins on all the film dielectrics shown here. Write to Cornell-Dubilier Electric Corporation, South Plainfield, New Jersey. *Manufacturers of consistently dependable capacitors, filters and networks for electronics, thermonucleonics, broadcasting and utility use for 50 years.*

*DuPont Reg. T.M.

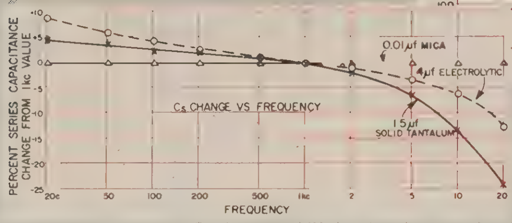
CDE **CORNELL-DUBILIER ELECTRIC CORPORATION**
AFFILIATED WITH FEDERAL PACIFIC ELECTRIC COMPANY



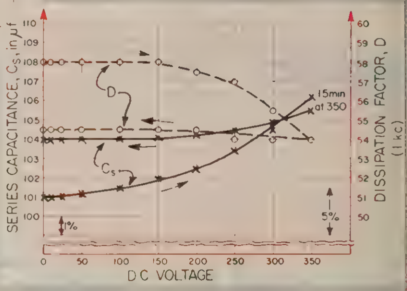
Characteristics of a variable-capacitance diode at 1 kc with forward and reverse biasing.



Behavior of an iron-core inductor a
various d-c levels. Measurements mad
with the Bridge in its "Orthonull" positio
to eliminate sliding balances which occu
when making low-Q measurements.

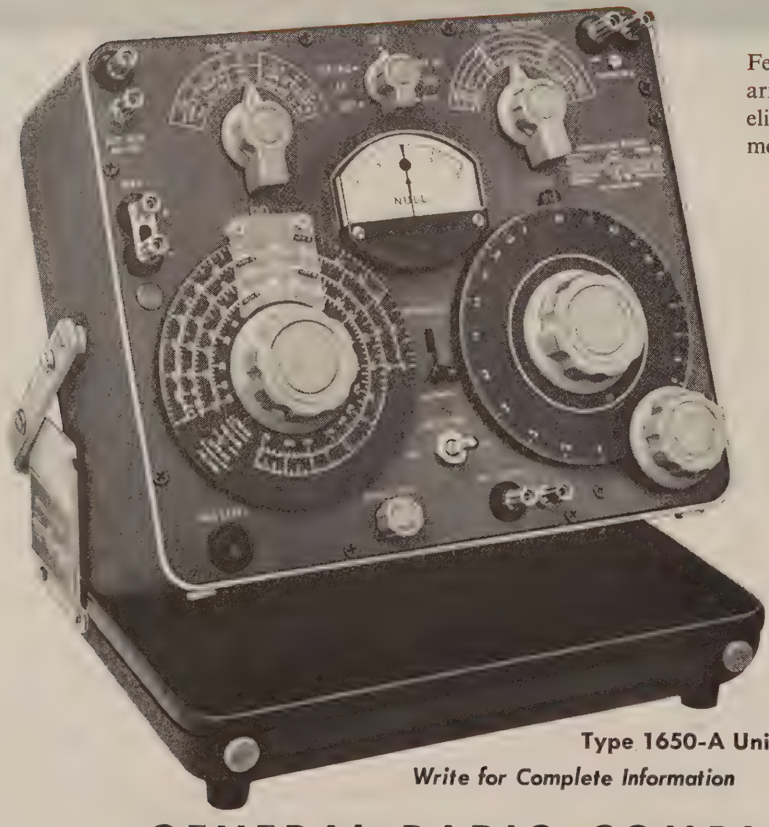


Plot of capacitance change vs frequency for three types of capacitors. External generator used is a G-R Type 1210-C Unit R-C Oscillator.



Variation of capacitance and dissipation factor of an unformed electrolytic as a function of d-c voltage as it is varied to rated voltage and then returned to zero.

These Measurements show why it's called a *Universal* IMPEDANCE BRIDGE



Features ***Orthonull,**** a unique mechanical gangin arrangement of the Bridge's variable elements tha eliminates sliding balances when making low-C measurements.

*U. S. Patent 2,872,63

- Completely self contained with built-in 1-kc oscillator an selective null detector . . . powered by four "D" batteries . . total drain is less than 10 ma, providing 1-year battery life fo typical laboratory use.
- Useful for measurements from 20c to 20 kc with externa generator.
- Unique cabinet design allows panel to be tilted to any con venient angle . . . closes and becomes a rugged carryin case for complete protection.
- Provision for applying polarization voltages to capacitors biasing voltages to diodes, and small currents to inductor for measurements at various d-c levels.
- **WIDE RANGES** —

  R: 0.001Ω to 10 MΩ **L**: 1 µh to 1000h
  C: 1 µµf to 1000 µf **D**: 0.001 to 50 at 1 kc
  Q: 0.02 to 1000 at 1 kc

- **ACCURACY** —

  1% for L and C from 20c to 20 kc
  1% for R from 20c to 5 kc
  5% for D and Q (ranges are a function of frequency)

Type 1650-A Universal Impedance Bridge . . . $450

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The first general purpose R-L-C Bridge was bu type 650-A which was introduced in 1933. It o successor designs, including the latest type 1650-A are in use in almost every electronics laborator and manufacturing plant today.

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in this issue

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- NOISE IN ELECTRONIC IMAGING
- PACKAGED TUNABLE MASER
- CADMIUM SULFIDE TRANSISTOR
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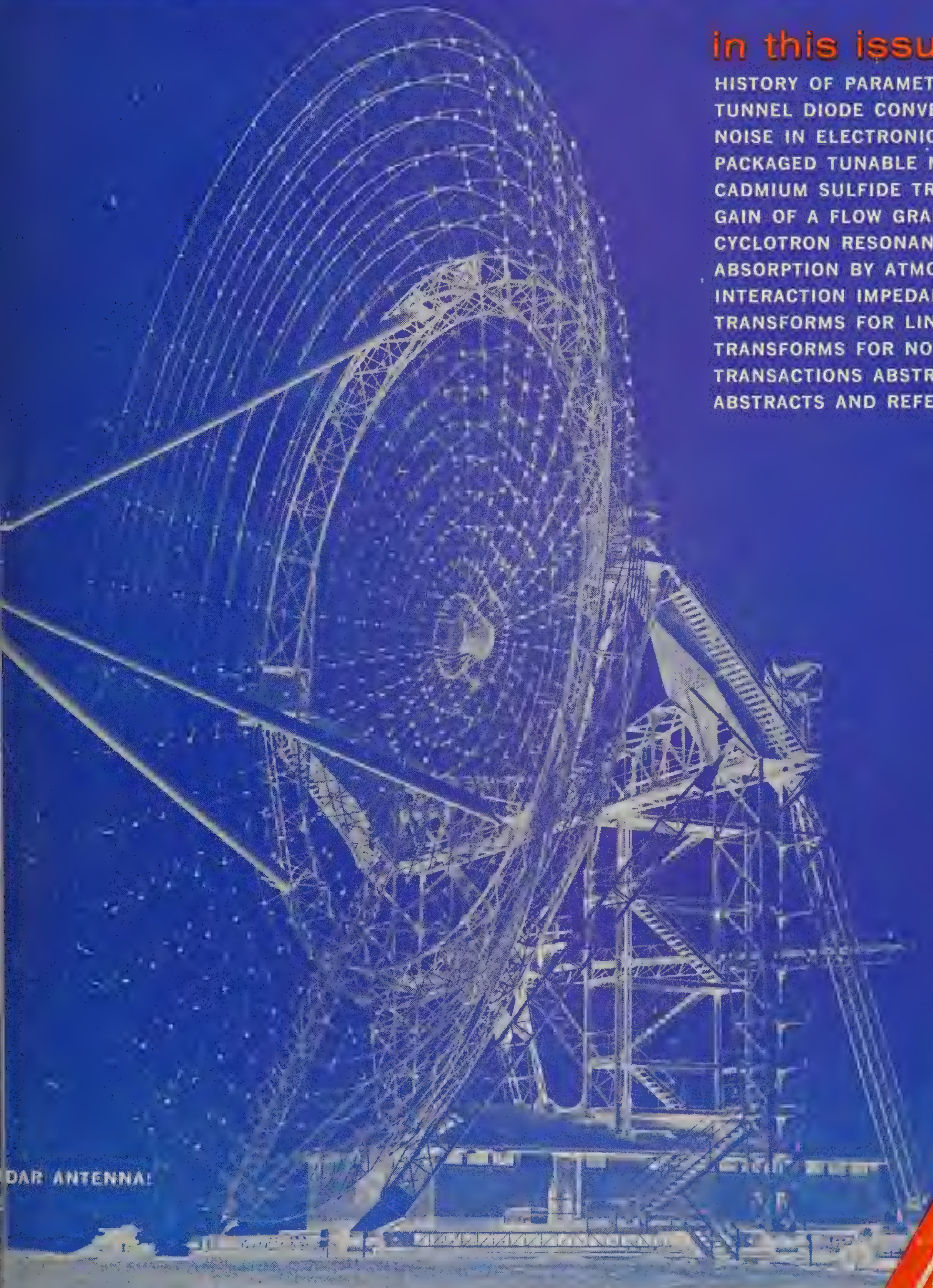

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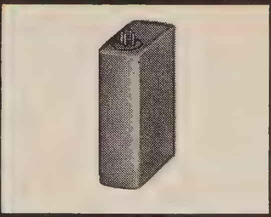
For Your Special Applications

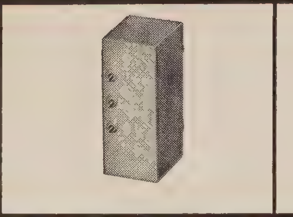
The bulk of UTC production is on special units designed to specific customers' needs. Illustrated below are some typical units and some unusual units as manufactured for special applications. We would be pleased to advise and quote to your special requirements.

FILTERS

All types for frequencies from .1 cycle to 400 MC.

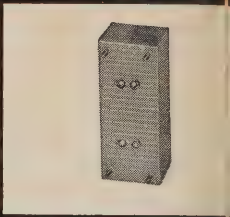


400 ∼ telemetering, 3 db at ± 7.5%, 40 db at 230 and 700 ∼, ⅝ x 1¼ x 2″



15 ∼ BP filter, 20 db at 30 ∼, 45 db at 100 ∼, phase angle at CF less than 3° from —40 to + 100° C.

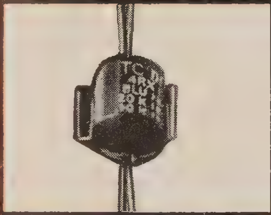
LP filter within 1 db to 49 KC, stable to .1 db from 0 to 85° C., 45 db at 55 KC.



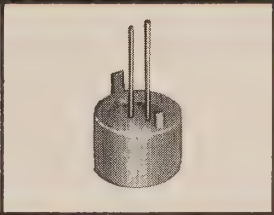
LP filter less than .1 db to 2.5 KC, 50 db beyond KC.

HIGH Q COILS

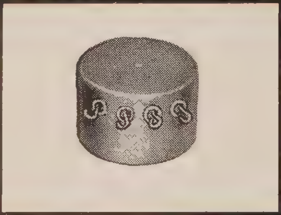
Toroid, laminated, and cup structures from .1 cycle to 400 MC.



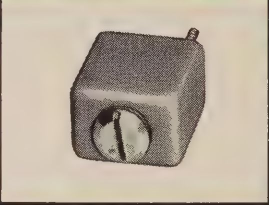
Tuned DO-T servo amplifier transformer, 400 ∼ .5% distortion.



Toroid for printed circuit, Q of 90 at 15 KC.



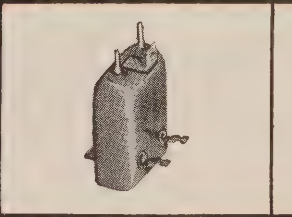
Dual toroid, Q of 75 at 10 KC, and Q of 120 at 5 KC.



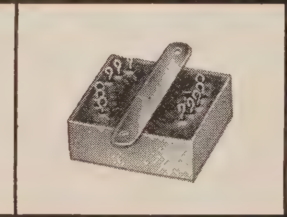
HVC tapped variable inductor for 3 KC oscillator.

SPECIALTIES

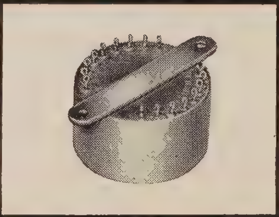
Saturable reactors, reference transformers, magnetic amplifiers, combined units.



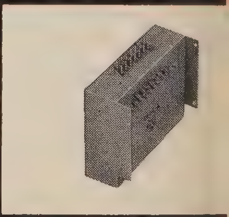
RF saturable inductor for sweep from 17 MC to 21 MC.



Voltage reference transformer .05% accuracy.



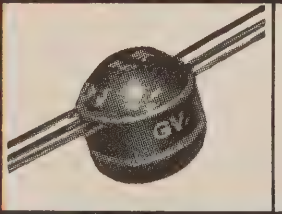
Multi-control magnetic amplifier for airborne servo.



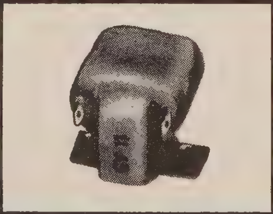
Input, output, two tune interstages, peaking ne work, and BP filter, all one case.

PULSE TRANSFORMERS

From miniature blocking oscillator to 10 megawatt.

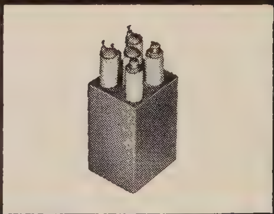


Wound core unit .01 microsecond rise time.



Pulse current tansformer 100 Amp.

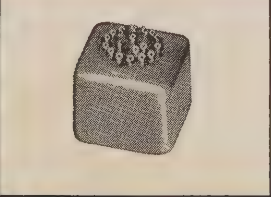
Pulse output to magnatron, bifilar filament.



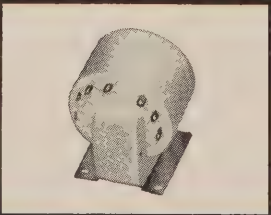
Precise wave shape pulse output, 2500 V. 3 Amps.

POWER COMPONENTS

Standard and high temperature . . . hermetic, molded, and encapsulated.

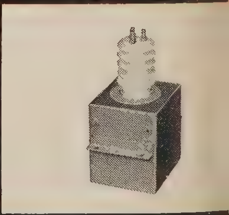


Multi-winding 140 VA, 6 KC power transformer 1¼ x 1¼ x 1″



200° C. power transformer, 400 ∼, 150 VA.

400 ∼ scope transformer, 20 KV output.



60 ∼ current limiting fil ment transformer, Sec. Mmfd., 30 KV hipot.

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May, 1960

published monthly by The Institute of Radio Engineers, Inc.

Proceedings of the IRE®

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The advent of more powerful and sensitive radars has led to novel proposals for studying the surface of the moon by radar, as reported in the Correspondence section of this issue. Shown on the cover is a 142-foot steerable parabolic antenna, the second largest in the world, located in Fraserburgh, Scotland. Built and operated by Stanford Research Institute under contract with the Rome Air Development Center, this antenna was used in the moon radar experiments reported on page 932.

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1960–1961
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B. J. Dasher (R3)
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J. B. Russell, Jr. (R1)

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In this article, Robert L. Sleven of our Department of Applied Electronics discusses a branch type *directional* filter and some surprising results of a study program.

Directional Filters

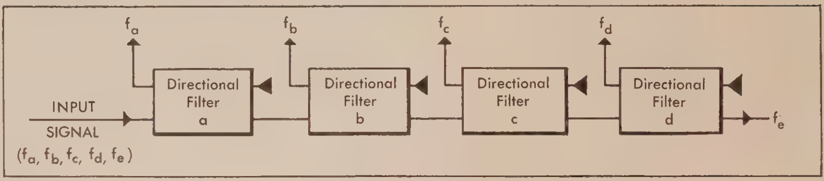

Figure 1. Directional Filter Multiplexer

The problem of "peeling off" the frequency components of an input signal as shown in Figure 1 is inherent in many countermeasures systems. While other types of filters have been used in the past, a rather unconventional filter appeared to offer several advantages. This filter (Figure 2) is a branch-type *directional* filter and its performance has recently been studied at AIL. The study program revealed the surprising result that many of the advantages of directional filters can be obtained if *one* and *only one* resonator is included in each branch.

The directional filter is a four-port network whose ideal responses are:

Port 1—Unity SWR
Port 1 to Port 2—
  Band-Pass Response
Port 1 to Port 3—
  Infinite Isolation
Port 1 to Port 4—
  Band-Reject Response

A network with the above performance is well-suited for multiplexing systems as can be seen from the block diagram shown in Figure 1. Signals at the resonant frequency of each directional filter will appear at the correct ports without any branching loss and the effect of one directional filter upon the other is negligible. This is not true with conventional branching filters.

The symmetry of the branch line directional filter is utilized to simplify the analysis of the four-port network by reducing it to an equivalent two-port. The overall network can be described as the product of three ABCD matrices. One of these matrices is for the filter network in each branch of the directional filter and the other two matrices are for lengths of transmission line corresponding to the spacing of the branches along the main transmission lines. In order to obtain theoretically the response stated above for each of the directional filter ports, certain conditions must be imposed on each of the matrices. High directivity (isolation of Port 3 from Port 1) is obtained when each branch of the directional filter is identical and the spacing of the branches is $(2n + 1)\ \lambda/4$ on one manifold and $(2n + 3)\ \lambda/4$ on the other manifold. To obtain the desired response at Ports 1, 2 and 4, conditions are imposed on the filter network which cannot be satisfied when each branch contains multiresonator filters. The filter network, in order to satisfy all conditions, must have identical driving point and transfer functions. This requirement can only be fulfilled when each branch of the directional filter contains one resonator. This result is significant because in the past it had been felt that as greater selectivity was required, more resonators would be used in each branch of the directional filter.

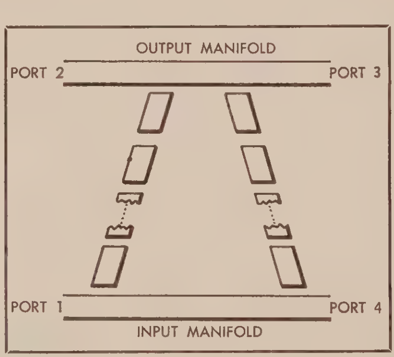

Figure 2. Branch Line Directional Filter

After having proved that ideal directional filter characteristics were not theoretically obtainable with multiresonator branches, the study continued until a suitable compromise in the response at each of the ports, was found, for the multiresonator case. The discrepancies between desired and obtainable directional filter performance differ depending upon the number of resonant elements in each branch. With an even number of dissipationless resonators in each branch, the power at resonance divides between Ports 2 and 4 and finite SWR exists at Port 1. With an odd number of resonant elements in each branch, the desired directional filter performance is obtained at resonance: that is, all power out Port 2. Except for the one resonator case, however, all directional filters with an odd number of resonators in each branch exhibit high SWR's at points in the passband.

The effect of dissipation on the directional filters performance is to mask some of the undesired characteristics and to magnify others. The passband SWR's are diminished in the presence of loss and the power out Port 4, which should be zero at resonance, becomes significant when dissipation is present.

The conclusions drawn from the directional filter study program were: (1) the ideal directional filter response listed above is theoretically obtainable when each branch consists of only one resonator and (2) when the selectivity of multiresonator filters is required, proper selection of filter decrements and coefficients of coupling will result in a directional filter response that is adequate for many purposes. The theoretical conclusions of the branch line directional filter program were verified experimentally by AIL.

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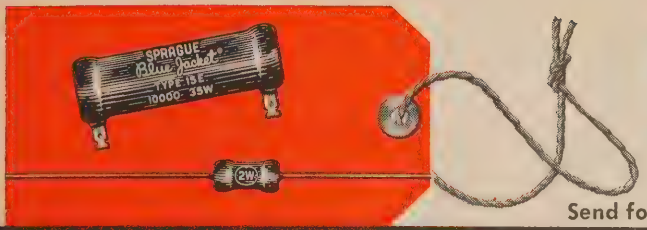
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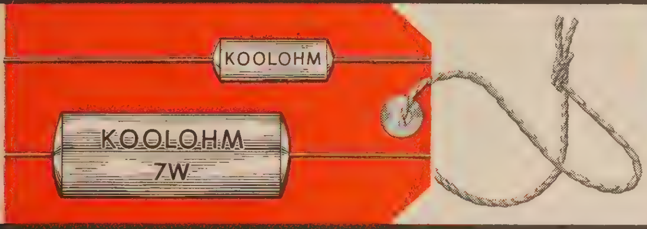
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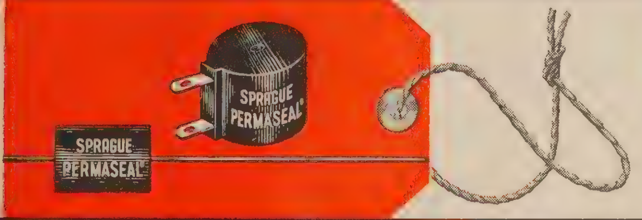
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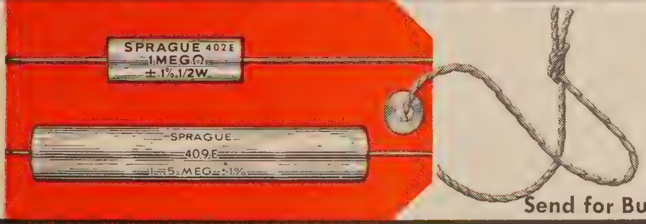
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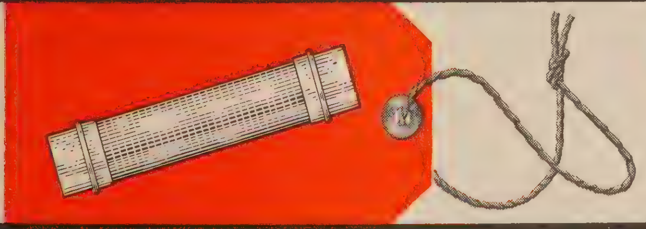

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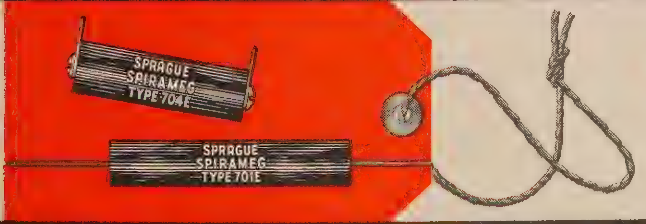
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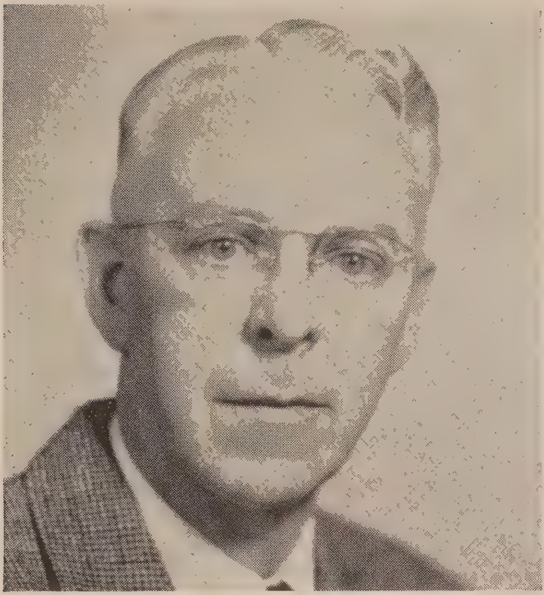

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A MAN WINS A MEDAL...AND STRENGTHENS A PHILOSOPHY

The search for the "hitherto unattainable" sometimes ends in strange places.

For years Bell Laboratories engineer Harold S. Black pondered a problem: how to rid amplifiers of the distortion which unhappily accumulated as signal-transmission paths were made longer and amplifiers were added. There had been many approaches but all had failed to provide a practical answer.

Then one day in 1927 the answer came—not in a research laboratory, but as he traveled to work on the Lackawanna Ferry. On a newspaper, Mr. Black jotted down those first exciting calculations.

Years later, his *negative feedback principle* had revolutionized the art of signal amplification. It is a principal reason why telephone and TV networks can now blanket the country, the transoceanic cable is a reality, and military radar and missile-control systems are models of precision.

For this pioneer achievement, and for numerous other contributions to communications since then (some 60 U. S. patents are already credited to him), Mr. Black received the 1957 Lamme Medal from the American Institute of Electrical Engineers. He demonstrated that the seemingly "unattainable" often *can* be achieved, and thus strengthened a philosophy that is shared by all true researchers.

He is one of many Bell Telephone Laboratories scientists and engineers who have felt the challenge of telephony and have risen to it, ranging deeply into science and technology. Numerous medals and awards have thus been won. Two of these have been Nobel Prizes, a distinction without equal in any other industrial concern.

Much remains to be done. To create the communication systems of the future, we must probe deeper still for new knowledge of Nature's laws. We must continue to develop new techniques in switching, transmission and instrumentation for every kind of information-bearing signal. As never before, communications offer an inspiring challenge to creative men.

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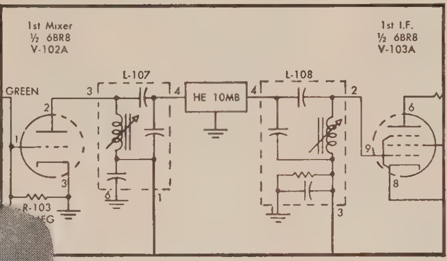

A portion of schematic diagram for AEROTRON 600 Series Receiver showing Hermes 10.7 Mc Crystal Filter at First Mixer.

Hermes Electronics Co.
CRYSTAL FILTER
10 MB
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AEROTRON, 600 Series, Two-way VHF-FM Radio Communications Equipment

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Meetings with Exhibits

As a service both to Members and the industry, we will endeavor to record in this column each month those meetings of IRE, its sections and professional groups which include exhibits.

△

May 23-25, 1960

1960 National Telemetering Conference, Miramar Hotel, Santa Monica, Calif.

Exhibits: Mr. William Van Dyke, Douglas Aircraft Co., Inc., El Segundo, Calif.

May 24-26, 1960

Seventh Regional Technical Conference & Trade Show, Olympic Hotel, Seattle, Wash.

Exhibits: Mr. Rush Drake, 1806 Bush Place, Seattle 44, Wash.

May 24-26, 1960

Armed Forces Communications & Electronics Association Convention and Exhibit, Sheraton-Park Hotel, Washington, D.C.

Exhibits: Mr. William C. Copp, 72 West 45th St., New York 36, N.Y.

June 20-21, 1960

Chicago Spring Conference on Broadcast and Television Receivers, Graemere Hotel, Chicago, Ill.

Exhibits: Mr. Stanley Hopper, Zenith Radio Corp., 6001 W. Dickens Ave., Chicago 39, Ill.

June 27-29, 1960

National Convention on Military Electronics, Sheraton-Park Hotel, Washington, D.C.

Exhibits: Mr. L. David Whitelock, BuShips, Electronics Div., Dept. of Navy, Washington, D.C.

August 1-3, 1960

Fourth Global Communications Symposium, Hotel Statler, Washington, D.C.

Exhibits: Mr. Robert O. Brady, Office of the Chief Signal Officer, U. S. Army Signal Corps, Washington, D.C.

August 23-26, 1960

WESCON, Western Electronic Show and Convention, Ambassador Hotel & Memorial Sports Arena, Los Angeles, Calif.

Exhibits: Mr. Don Larson, WESCON, 1435 LaCienega Blvd., Los Angeles, Calif.

September 19-21, 1960

National Symposium on Space Electronics & Telemetry, Shoreham Hotel, Washington, D.C.

Exhibits: Mr. Leon King, Jansky and Bailey, 1339 Wisconsin Ave., N.W., Washington, D.C.

October 3-5, 1960

Sixth National Communications Symposium, Hotel Utica & Utica Municipal Auditorium, Utica, N.Y.

Exhibits: Mr. R. E. Bischoff, 19 Westminster Road, Utica, N.Y.

(Continued on page 10A)

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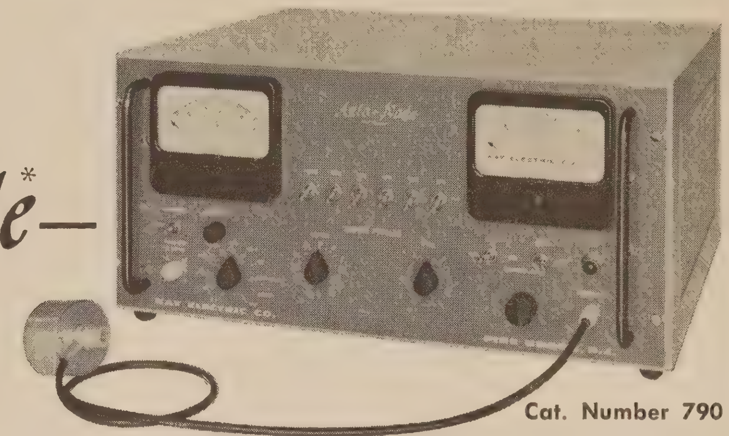

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Mega-Node 3000	1-3000	0-20	unbalanced—50	$790.00
Rada-Node® 600-A	5-400	0-23.8 depending on impedance	unbalanced as specified	$1495.00
	10-3000	0-20	unbal. nom. 50	$1965.00
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SP-13	Interstage	20000/30000 c.t.	800/1200 c.t.
SP-15	Interstage	10000/12000 c.t.	1500/1800 c.t.

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Meetings with Exhibits

(Continued from page 8A)

October 10-12, 1960

National Electronics Conference, Hotel Sherman, Chicago, Ill.

Exhibits: National Electronics Conference, Inc., 228 North La Salle St., Chicago 1, Ill.

October 24-26, 1960

East Coast Aeronautical & Navigational Electronics Conference, Lord Baltimore Hotel & 7th Regiment Armory, Baltimore, Md.

Exhibits: Mr. R. L. Pigeon, Westinghouse Electric Corp., Air Arm Div., P.O. Box 746, Baltimore, Md.

October 26-28, 1960

Fifth Annual Conference on Non-Linear Magnetics and Magnetic Amplifiers, Bellevue-Stratford Hotel, Philadelphia, Pa.

Exhibits: J. L. Whitlock Associates, 6044 Ninth St., North, Arlington 5, Va.

Oct. 31-Nov. 2, 1960

13th Annual Conference on Electrical Techniques in Medicine & Biology, Sheraton-Park Hotel, Washington, D.C.

Exhibits: Mr. Lewis Winner, 152 West 42nd St., New York 36, N.Y.

November 15-16, 1960

Mid-America Electronics Convention (MAECON), Hotel Muehlebach, Kansas City, Mo.

Exhibits: Mr. Gustav Vasen, H. A. Roes Co., 2106 Cherry, Kansas City 8, Mo.

November 15-17, 1960

Northeast Electronics Research & Engineering Meeting (NEREM), Boston Commonwealth Armory, Boston, Mass.

Exhibits: Miss Shirley Whitcher, IRE Boston Office, 73 Tremont St., Boston, Mass.

December 1-2, 1960

PGVC Annual Meeting, Sheraton Hotel, Philadelphia, Pa.

Exhibits: Mr. E. B. Dunn, Atlantic Refining Co., 260 S. Broad St., Philadelphia 1, Pa.

December 11-14, 1960

Eastern Joint Computer Conference, Hotel New Yorker, New York, N.Y.

Exhibits: J. L. Whitlock Associates, 6044 Ninth St., North, Arlington 5, Va.

▲

Note on Professional Group Meetings: Some of the Professional Groups conduct meetings at which there are exhibits. Working committeemen on these groups are asked to send advance data to this column for publicity information. You may address these notices to the Advertising Department and of course listings are free to IRE Professional Groups.

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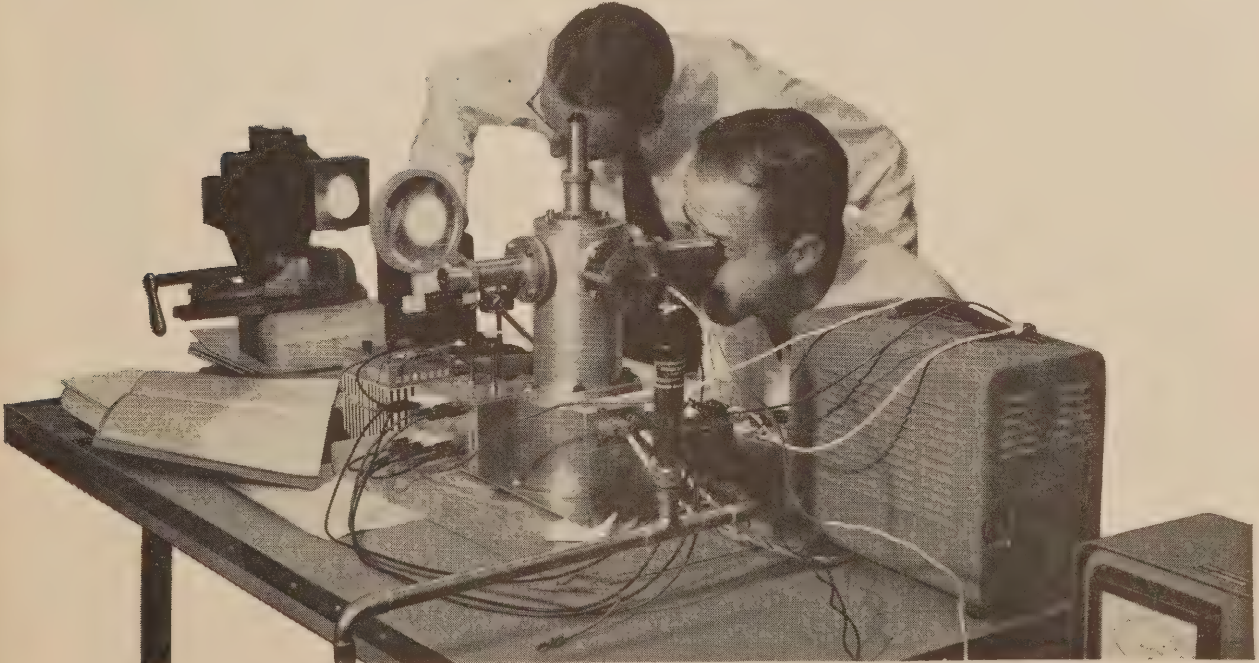
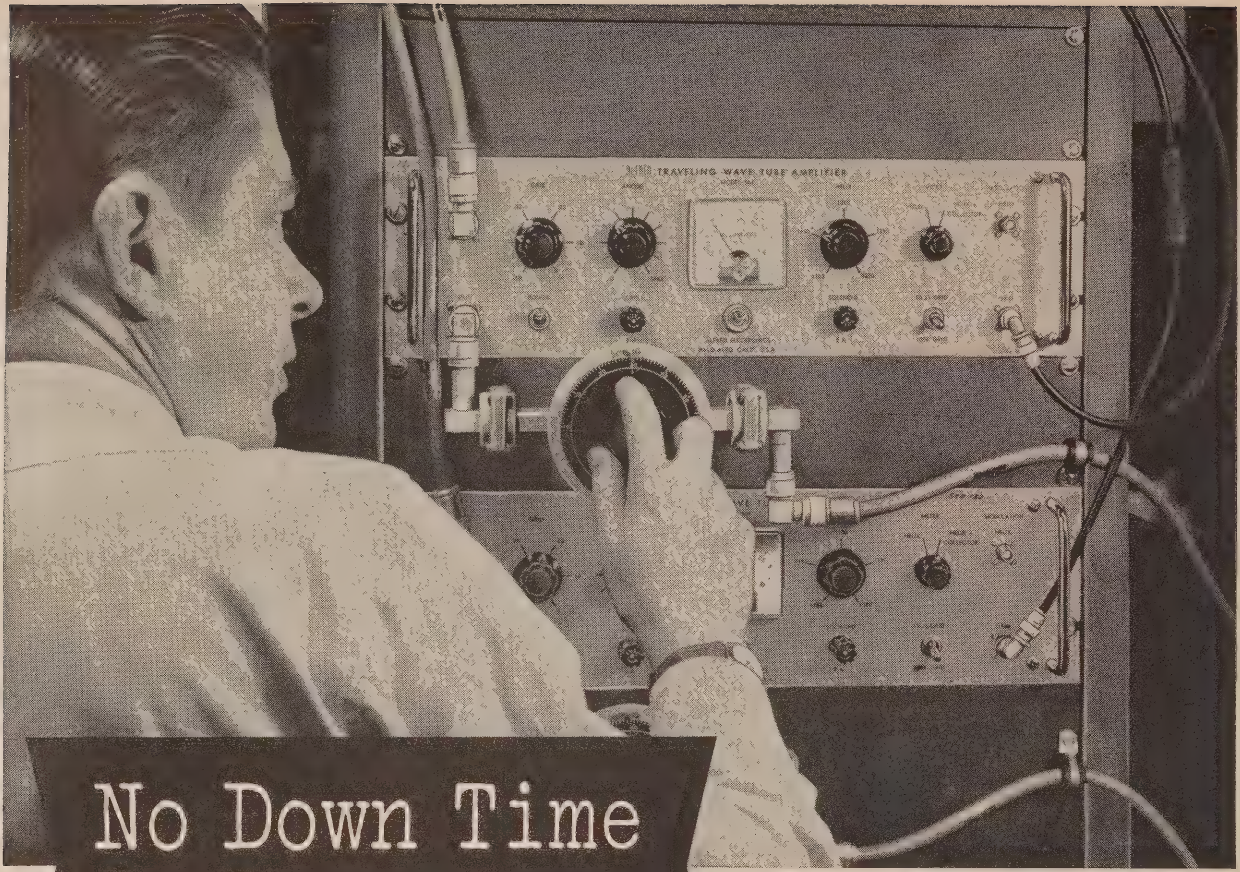


An electron device permits scientists to study the behavior of charged dust particles held in suspension.



No Down Time Is Normal . . .

Alfred Electronics Model 504 Microwave Amplifiers, in use at Hughes Aircraft Co., Culver City, California

*with **ALFRED** Microwave Amplifiers*

These Alfred TWT microwave amplifiers have seen continuous service at Hughes for over 9 months. There has been practically no down time even for replacement of TWT tubes. Used in the RF portion of a missile testing system, the Alfred units provide high gain, wide band, flat response and low spurious modulation from 8 to 12.4 kmc. Hughes engineers praise the functional layout of the Model 504, its simple operation and reliable performance.

In short, Hughes finds the Alfred 504 Microwave Amplifiers good, sound, straightforward reliable instruments. We think you will too.

KEY SPECIFICATIONS—ALFRED MICROWAVE AMPLIFIERS

	Model	Frequency Range kmc	Gain db (min)	Power Output (min)	Price
General Purpose Amplifiers for AM, Pulse and Phase Modulation	505	1 to 2	30 db	10 mw	$1,550
	501	2 to 4			$1,390
	503	4 to 8			$1,490
	504	8 to 12.4			$1,490
	549	10.5 to 16			$3,550
Medium Power Amplifiers	5-6752	1 to 2	30 db	1 w	$2,290
	512	2 to 4	30 db	1 w Pulsed	$1,850
			20 db	100 mw CW	
	502	2 to 4	30 db	1 w	$1,390
	5-6868	2 to 4	30 db	10 w	$2,850
	506	4 to 8 4.5 to 7.5	27 db	.5 w 1 w	$2,290
	5-542	4 to 8	25 db	1 w	$3,190
	510	8 to 12.4	20 db	100 mw	$2,150
	509	8.2 to 11	27 db	.5 w	$3,150
	5-6996	8 to 9.6	30 db	10 w	$3,590
High Power Amplifiers	5-6826	2 to 4	30 db	1 kw pk	$4,850
Low and Medium Noise Figure Amplifiers	Amplifiers with low and medium noise figures are available either as packaged units or unitized for remote operation of TW tube and solenoid. Standard units provide coverage from .5 to 12.4 kmc with noise figures from 7 db up.				

MANY MODELS TO CHOOSE FROM

The 504 is just one model from the industry's most complete line of microwave amplifiers. For technical details and a demonstration arranged at your convenience, contact your nearby Alfred representative or write direct. Please address . . .

ALFRED ELECTRONICS
897 COMMERCIAL STREET
PALO ALTO, CALIFORNIA 5
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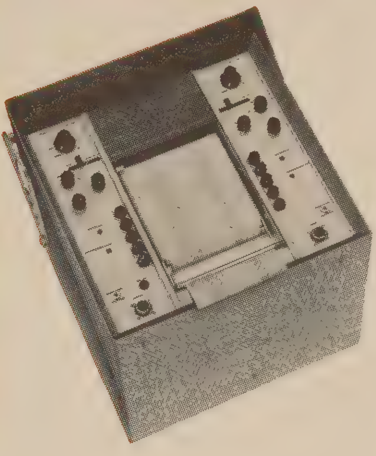
keep an accurate graphic record

OF RESEARCH, DESIGN, TEST DATA

two channels



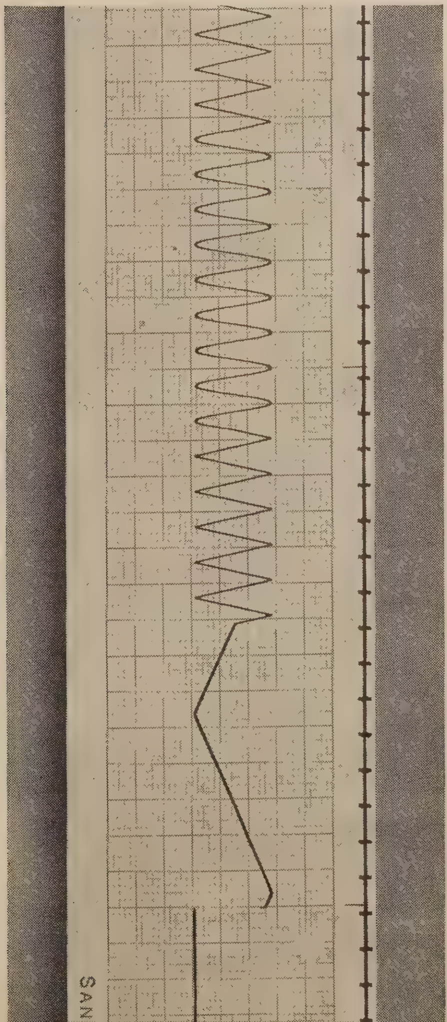
For General Purpose DC Recording — Model 320

For recording *two variables* simultaneously, the Model 320 provides a versatile, transistorized amplifier for each input signal. The rugged 2-channel recorder assembly has heated stylus recording on two *50 mm wide* rectangular coordinate channels, 4 pushbutton chart speeds, and 6 inches of visible chart. The Recorder can be placed vertically, horizontally or at a 20° angle.

MODEL 320 SPECIFICATIONS

Sensitivity: 0.5, 1, 2, 5, 10, 20 mv/mm and v/cm
Frequency Response: 3 db down at 125 cps, 10 mm peak-to-peak
Common Mode Voltage: ±500 volts max.
Common Mode Rejection: 140 db min. DC
Calibration: 10 mv internal ±1%
Output Connectors for each channel accept external monitoring 'scope or meter
Price: $1495

NEW SANBORN PORTABLE DIRECT WRITING RECORDERS FOR IN-PLANT, LABORATORY OR FIELD RECORDING



Two models of this 21 lb. brief case size recorder are available — Model 301 for AC strain gage recording, Model 299 for general purpose DC recording. Both provide immediately visible, inkless traces by heated stylus on 40 division rectangular coordinate charts . . . frequency response to 100 cps . . . 5 and 50 mm/sec chart speeds . . . approx. 4 inches of record visible in top panel window.

single channel

MODEL 301 SPECIFICATIONS

The amplifier section of the Model 301 is an all-transistorized carrier type with phase sensitive demodulator. The power supply and internal oscillator circuits are also transistorized.
Sensitivity: 10 uv rms/div (from transducer)
Attenuator Ratios: 2, 5, 10, 20, 50, 100, 200
Carrier Frequency: 2400 cps internal
Transducer Impedance: 100 ohms min.
Calibration: 40 uv/volt of excitation
Output Connector: for external monitoring 'scope or meter
Price: $750

MODEL 299 SPECIFICATIONS

Combines the dependability of transistors with the high input impedance of vacuum tubes for reliable broad-band DC recording.
Sensitivity: 10, 20, 50, 100, 200, 500 mv/div and 1, 2, 5 and 10 v/div
Input Resistance: 5 megohms balanced each side to ground
Common Mode Voltage: ±2.5 volts max. at 10 mv/div sensitivity increasing to ±500 volts max. at other sensitivities
Common Mode Rejection: 50:1 most sensitive range
Calibration: 0.2 volt internal ±1%
Output Connector: for external monitoring 'scope or meter
**Price: Model 299 (with zero suppression) $700
Model 299A (without zero suppression) $650**

All prices are F. O. B. Waltham, Mass., within continental U. S. A. and are subject to change without notice.

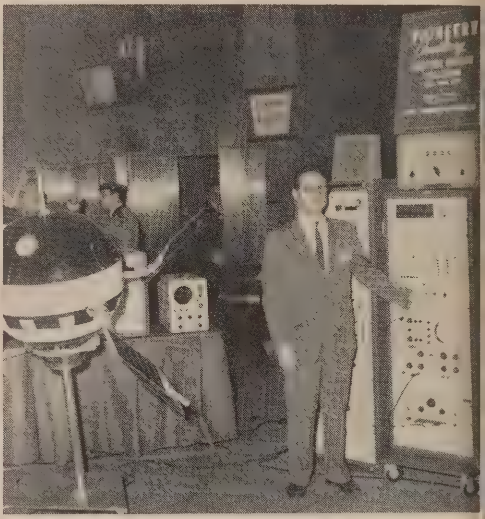
Contact your Sanborn Sales-Engineering representative for complete information, or write the main office in Waltham. Sales-Engineering representatives are located in principal cities throughout the United States, Canada and foreign countries.

SANBORN COMPANY
INDUSTRIAL DIVISION
175 Wyman Street, Waltham 54, Mass.

1960 INTERNATIONAL IRE CONVENTION

Record 69,760 Attendance

Engineers at the opening of the IRE Convention in the Colliseum gather around the Pioneer V auxiliary control station which was designed, assembled and operated by Space Technology Laboratories, Inc. Contact was made with Pioneer V a few moments after this picture was taken.



Dr. George Mueller, Vice President of Space Tec
nology Labs., Inc., about to initiate a command sign
from the control station in the lobby of the Coliseu
The command was sent by transatlantic cable to th
Jodrell Bank radio telescope in England, which r
layed the command to Pioneer V, which at the m
ment was1, 448,000 miles from the earth. Pioneer V
response came back to the Coliseum by the same rout
At the left is a full-scale model of Pioneer V.

One of the highlights of the technical program was a seminar on the 1959 International Radio Conference in Geneva. Participants were (*left to right*) Rosel H. Hyde, FCC Commissioner; Francis C. de Wolf, Chief, Telecommunications Division, Department of State; T. A. M. Craven, FCC Commissioner; Arther L. Lebel, Assistant Chief, Telecommunications Division, Department of State; and Edward W. Allen, Jr., Chief Engineer, FCC.

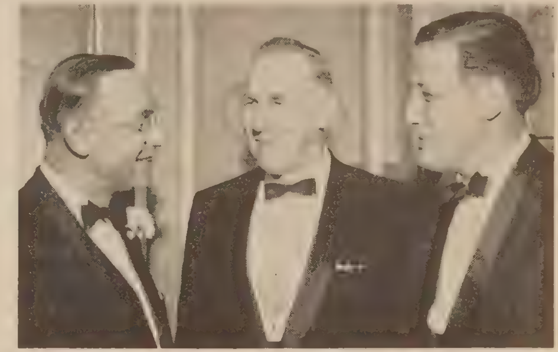
Retiring IRE President, Ernst Weber, hands the gavel of office to the incoming IRE President, R. L. McFarlan at the Annual Meeting held in the Grand Ballroom of the Waldorf-Astoria Hotel.

IRE Officers present at the Convention (seated, *left to right*): G. W. Bailey, Executive Secretary; Ferdinand Hamburger, Jr., Editor; John N. Dyer, Vice President; and L. V. Berkner, Director and Speaker at the Annual Meeting. Standing, *left to right*, are Ernst Weber, Junior Past President; R. L. McFarlan, President; and Haraden Pratt, Secretary.

WHERE TOMORROW IS TODAY

A view of some of the exhibits at the Coliseum, topped by the theme of the Radio Engineering Show, "Where Tomorrow is Today." There were 856 exhibitors at the Show, with 25,000 items on display.

The speaker's table at the Annual IRE Banquet, held in the Grand Ballroom of the Waldorf-Astoria Hotel.



Eric Walker, President of Pennsylvania State University, spokesman for the new Fellows; H. I. Romnes, President of Western Electric, principal speaker; and B. M. Oliver, Vice President, Hewlett-Packard, Co., toastmaster, at the Annual Banquet.

(*Left*) IRE President R. L. McFarlan presents the Founder's Award to Haraden Pratt, left, and the Medal of Honor to Harry Nyquist, right, at the Annual Banquet.

(*Right*) President McFarlan presents the Morris Liebmann Memorial Prize to J. A. Rajchman, the Browder J. Thompson Memorial Prize to J. W. Gewartowski, and the Harry Diamond Memorial

IRE News and Radio Notes

CURRENT IRE STATISTICS

(As of March, 31, 1960)

Membership—80,274
Sections*—105
Subsections*—27
Professional Groups*—28
Professional Group Chapters—263
Student Branches†—187

* See this issue for a list.
† See October, 1959 issue for a list.

Calendar of Coming Events and Authors' Deadlines*

1960

- **Natl. Aeronautical Electronics Conf., Dayton-Biltmore and Miami Hotels, Dayton, Ohio, May 1–3.**
- **URSI-IRE Spring Mtg., Sheraton Park Hotel and NBS, Washington, D. C., May 2–5.**
- Western Joint Computer Conf., San Francisco, Calif., May 2–6.
- Symp. on Graduate Programs in Bio-Medical Engrg., Univ. of Vermont, Burlington, May 5–6.
- **PGMTT Natl. Symp., San Diego, Calif., May 9–11.**
- **Electronic Components Conf., Hotel Washington, Washington, D. C., May 10–12.**
- **Natl. Telemetering Conf., Miramar Hotel, Santa Monica, Calif., May 23–25.**
- **7th Reg. Tech. Conf. & Trade Show, Olympic Hotel, Seattle, Wash., May 24–26.**
- **6th Radar Symp., Ann Arbor, Mich., June 1–3.**
- Inst. on Recent Advances in Solid State Devices, Marquette Univ., Milwaukee, Wis., June 1–2.
- 10th Ann. Conv. of Soc. of Women Engrs., Benjamin Franklin Hotel, Seattle, Wash., June 9–11.
- **Radio Frequency Interference Symp., Shoreham Hotel, Washington, D.C., June 13–14.**
- **Chicago Spring Conf. on Broadcast and Television Receivers, Graemere Hotel, Chicago, Ill., June 20–21.**
- **Conf. on Standards and Electronic Measurements, NBS Boulder Labs., Boulder, Colo., June 22–24.**
- **Workshop on Solid State Electronics, Purdue Univ., Lafayette, Ind., June 23–24.**
- **Natl. Conv. on Mil. Elec., Sheraton Park Hotel, Washington, D. C., June 27–29.**
- **Cong. Intl. Federation of Automatic Control, Moscow, USSR, June 25–July 9.**
- **Int'l Conf. on Electrical Engrg. Education, Sagamore Conf. Center, Syracuse Univ., Syracuse, N. Y., Jul.**
- 7th Ann. Symp. on Computers and Data Processing, Stanley Hotel, Estes Park, Colo., July 28–29.

* DL=Deadline for submitting abstracts.

(*Continued on page 18A*)

BENELUX SECTION TO CONDUCT DATA TRANSMISSION SYMPOSIUM

The Benelux Section of the IRE has announced an International Symposium on Data Transmission, to be held at Delft, Netherlands, on September 19 and 20, 1960. The symposium will be concerned with the problems of transmitting and receiving information in digital form. Particular emphasis will be placed on the behavior of practical communication networks—including existing telephone systems, existing and planned military systems, and schemes of the future, such as those that use satellites. Appropriate topics include the choice of modulation, the application of coding, the demands of channel users, the design of new systems and the improvement of old, the behavior of links and networks under test, and the selection of models for further study. The aim will be to reduce the gap now existing between theory and practice.

The symposium will be conducted in English. Papers already promised indicate good representation of the work being carried on in the USA, as well as that conducted in Europe. The Symposium Committee consists of H. C. A. van Duuren, Chairman, B. B. Barrow, H. Rinia, and F. L. Stumpers. All correspondence regarding the symposium should be addressed to B. B. Barrow, Secretary, The Benelux Section of the IRE, Postbus 174, Den Haage, Nederland.

FIRST ARMY MARS NET PRESENTS MAY SPEAKERS

With the presentation of its May Speaker Schedule, the First U. S. Army MARS SSB Technical Net will recess its weekly series of technical talks and forum until September of this year. The Net meets on 4030 kc each Wednesday at 9:00 P.M. EDT. The schedule for May includes:

May 4	"Antenna Panel," W. Offutt, Engineering Manager; L. De Size, Group Leader and B. Woodward, Engineer—Airborne Instrument Labs, Inc., Melville, L. I., N. Y.
May 11	"Frequency Control," Dr. G. Winkler, Scientist USARDL, Fort Monmouth, N. J.
May 18	"Communication Electronic Needs of the Future," Dr. J. V. Harrington, Division Head, and Dr. B. Lax, M.I.T. Lincoln Lab., Lexington, Mass.
May 25	"Fundamentals of Oscillator Operation," R. W. Gunderson, Editor, Braille Technical Press, New York, N. Y.

NBS HEAD HONORED BY CIVIL SERVICE LEAGUE

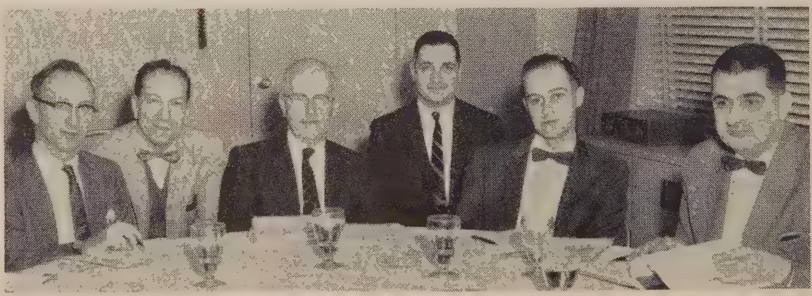
Allen V. Astin (SM'50–F'54), Director of the National Bureau of Standards, has been selected by the National Civil Service League as one of the top ten career employees in the Federal civil service for 1960. The Award was presented to Dr. Astin at a dinner in Washington, D. C., on March 15.

The League, a non-partisan citizens' organization for better government through better personnel, this year will give its sixth series of Career Service Awards to ten Federal employees chosen for competence, character and achievement.

Dr. Astin has been in government 27 years. A native of Salt Lake City, Utah, with degrees from the University of Utah, New York University, Lehigh and George Washington, he now lives in Bethesda, Md.

Joining the Bureau of Standards in 1932, he was active for eight years in research in the Heat and Power and Electricity Divisions, and during the next eight became successively Chief of the Optical Fuze Section and the Ordnance Development Division. He was promoted to Director of the Bureau in 1952.

Among his scientific contributions are the discovery and development of improved methods of measuring dielectric constants and power factors of dielectric materials; pioneering work in developing radio telemetering techniques and instruments, especially applied to meterological and cosmic ray problems; and contributions to the development and evaluation of proximity fuzes. His record of publications begins in 1929 and has continued productively. He has served on many committees and boards, such as the Defense Science Board, International Committee of Weights and Measures, and National Advisory Committee for Aero-



At a recent meeting of the national committee of the 13th Annual Conference on Electrical Techniques in Medicine and Biology, in the Sheraton Hotel, Philadelphia, Pa., where plans for the forthcoming Washington, D. C., conference (October 31, November 1–2) were made, *left to right:* A. L. Henley, secretary; Lewis Winner, public relations-exhibits; L. E. Flory, editorial board; A. Shapero, treasurer; G. N. Webb, program chairman and R. L. Bowman, conference chairman.

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Life — up to 500 hours guaranteed — over 3000 hours reported
Frequency stability — less than 2 Mc drift per 100 hours (C band)
Power stability — drop of less than 1 db for constant voltage input
Duty cycle stability — less than 3 Mc frequency shift for a change in duty cycle of 0.00005 to 0.002 (C band)
Vibration — less than 2.5 Mc frequency shift from 55 to 2000 cps
Shock — withstands 100 g's of 6 millisecond duration
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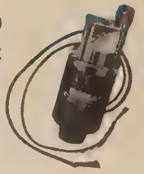
Miniaturized
Tunable over a broad band



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Band	Tube Type	Fixed Freq. or Tunable	Frequency Range Mc	Min. Peak Power Watts	Outptut Mates With
C	BL-212	Tunable	5400-5900	100	UG699/U
C	BL-243	Tunable	5400-5900	200	UG699/U
C	BL-242	Tunable	5400-5900	400	N
C	BLM-022	Tunable	5400-5900	500	TNC
C	BLM-026	Tunable	5400-4900	500	TNC
C	BLM-020	Tunable	5400-5900	700	TNC
C	BL-245	Tunable	5400-5900	900	TNC
C	BL-250	Tunable	5400-5900	150	TNC
X	BLM-003	Tunable	9000-9500	150	TNC
X	BLM-014	Tunable	8500-9000	150	TNC
X	BLM-012	Tunable	8900-9400	1000	TNC
X	BLM-021	Tunable	8900-9400	1000	UG40A/U
X	BLM-024	Tunable	9300-9500	150	TNC

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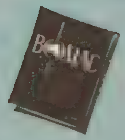

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Calendar of Coming Events and Authors' Deadlines*

(Continued from page 16A)

4th Global Communications Symp., Hotel Statler, Washington, D. C., Aug. 1–3.

AIEE Pacific Gen. Mtg., El Cortez Hotel, San Diego, Calif., Aug. 9–12.

WESCON, Los Angeles Mem. Sports Arena, Los Angeles, Calif., Aug. 23–26.

URSI 13th Gen. Assembly, Univ. of London, London, Eng., Sept. 5–15.

Joint Automatic Control Conf., M.I.T., Cambridge, Mass., Sept. 7–9.

Conf. on Communications, Roosevelt Hotel, Cedar Rapids, Iowa, Sept. 9–10.

4th Ann. Joint Mil. Ind. Electronic Test Equip. Symp., Chicago, Ill., Sept. 14–15.

Space Electronics and Telemetry Conv. and Symp., Shoreham Hotel, Washington, D.C., Sept. 19–22.

Industrial Elec. Symp., Manger Hotel, Cleveland, Ohio, Sept. 21–22,

Sixth Natl. Communications Symp., Hotel Utica and Utica Municipal Aud., Utica, N. Y., Oct. 3–5. (DL*: June 1, B. H. Baldridge, 25 Bolton Rd., New Hartford, N. Y.)

PGNF 7th Ann. Mtg, Gatlinburg, Tenn., Oct. 3–5.

Natl. Elec. Conf., Hotel Sherman, Chicago, Ill., Oct. 10–12. (DL*: May 1960 Prof. T. F. Jones, Jr., School of E.E., Purdue Univ., Lafayette, Ind.)

Engrg. Writing and speech Symp., Bismark Hotel, Chicago, Ill., Oct. 13–14.

Symp. on Space Navigation, Deshler-Hilton Hotel, Columbus, Ohio, Oct. 19–21, (DL*: July 15, J. D. Kraus, Ohio State Univ. Radio Observatory, Columbus.)

East Coast Conf. on ANE, Lord Baltimore Hotel, Baltimore, Md., Oct. 24–26. (DL*: June 6, S. Hershfield, The Martin Co., Baltimore, Md.)

5th Ann. Conf. on Nonlinear Magnetics and Magnetic Amplifiers, Bellevue-Stratford Hotel, Philadelphia, Pa.

Electron Devices Mtg., Hotel Shoreham, Washington, D. C., Oct. 27–29.

13th Ann. Conf. on Elec. Tech. in Med. and Bio., Sheraton Park Hotel, Washington, D. C., Oct. 31, Nov. 1–2.

Radio Fall Mtg., Hotel Syracuse, Syracuse, N. Y., Oct. 31, Nov. 1–2.

6th Ann. Conf. on Magnetism and Magnetic Materials, New Yorker Hotel, N. Y., N. Y., Nov. 14–17.

Mid-Amer. Elec. Conv., Hotel Muehlebach, Kansas City, Mo., Nov. 15–16. (DL*: June 15, J. Austin, Bendix Aviation Corp., 95 and Troost, Kansas City, Mo.)

PGPT Ann. Conf., Boston, Mass., Nov. 15–16. (DL*: June 1, C. W. Watt, Raytheon Co., Waltham, Mass.)

1960 NEREM (Northeast Electronics Res. & Engrg. Mtg.), Boston, Mass., Nov. 15–17.

PGVC Ann. Mtg., Sheraton Hotel, Philadelphia, Pa., Dec. 1–2, (DL*: July 15, W. G. Chaney, American Telephone and Telegraph Co., 195 Broadway, N. Y. 7, N. Y.)

Eastern Joint Computer Conf., New Yorker Hotel, New York, N.Y., Dec.

* DL = Deadline for submitting abstract.

nautics. He has had a leading role in government science programs and the direction of national and international science activities. His awards include the Presidential Certificate of Merit and His Majesty's Medal for Service in the Cause of Freedom.

NATIONAL SCIENCE FOUNDATION ESTABLISHES ADVISORY PANEL

A temporary Advisory Panel on Radio Telescopes has been appointed by the National Science Foundation. The purpose of the Panel is to 1) study the present and predictable needs of radio astronomers with regard to improved instrumentation; 2) study existing and proposed instruments with regard to their capabilities and limitations and 3) advise the Foundation with regard to the desirability and feasibility of more powerful instruments. The members of the Panel are Dr. J. R. Pierce, Bell Telephone Laboratories, Chairman; Dr. R. N. Bracewell, Stanford University; Dr. P. E. Chenea, Purdue University; Dr. L. J. Chu, Massachusetts Institute of Technology; Dr. R. M. Emberson, Assoc. Universities, Inc.; Dr. W. E. Gordon, Cornell University; Dr. D. S. Heeschen, National Radio Ast. Obs.; Dr. R. Minkowski, Mt. Wilson and Palomar Obs.; Dr. G. W. Swenson, Jr., University of Illinois; J. H. Trexler, Naval Research Lab. Scientists and engineers wishing to bring their ideas to the attention of the panel are encouraged to communicate them (to the panel members or directly) to the Astronomy Program, National Science Foundation.

CORNELL UNIVERSITY TO HOLD JUNE SEMINARS

The annual Industrial Engineering Seminars are being presented for the seventh successive year at Cornell University during June 14–17, 1960. Seminars will be conducted in seven major areas. Of these, those of interest to radio and electronics engineers will be the seminars in Engineering Administration, Systems Simulation Using Digital Computers, Statistical Decision-Making: Theory and Applications, and in Statistical Reliability Analysis: Theory and Applications.

The seminar series on Engineering Administration has been planned for persons responsible for the administration of engineering and applied research activities. Topics to be discussed include a) communication problems in the technical organization, b) manpower planning and the growing shortage of engineers, c) the development of engineers as supervisors, d) creativity through group effort, e) directing engineering programs, f) engineering program planning, g) the management of technical services, and h) cost control of engineering projects.

The seminar group on Statistical Reliability Analysis: Theory and Application will provide a current survey of statistical theory and techniques on reliability analysis that are being developed to meet the growing demands for improved materials and component reliability. It is intended for those engineers and manufacturing executives whose responsibilities include predicting and implementing the economic balance of product quality against cost through environmental destruction tests, marginal checking and failure analysis. Among the topics to be discussed will be: a) statistical aspects of experimentation, b) statistical theory of reliability based on failure models such as the exponential, Weibull, gamma and extreme-value, c) techniques of analyzing failure data, d) the improvement of reliability through redundancy and maintenance, e) the design of life-testing experiments, f) selection and ranking problems, and g) unsolved problems in reliability.

The use of simulated experimentation in the analysis and design of complex systems is one of the most promising of the applications of high-speed digital computers. The series of seminar sessions on Systems Simulation Using Digital Computers will explore this expanding field and consider problems in constructing the program, in using a simulator and in analyzing results. The topics for discussion will include a) the experimental investigation of complex systems, b) equipment requirements for digital simulation, c) the logical representation of an operating system, d) the construction of a computer program to simulate a simple system, e) problems in the design of a simulation experiment, f) experimental determination of

In preparation for the 1960 IRE 7th Regional Conference, Dr. D. K. Reynolds, Technical Program Chairman (*far right*) explains to other IRE committee chairmen the three major fields which the conference attendants will study. The conference, to be held in Seattle on May 24–26, will feature studies of control systems, solid state electronics, and electromagnetics. The other IRE conference chairmen include (*left to right*) W. T. Harrold, Public Relations Chairman; Rush Drake, Electronics Exhibit Chairman; Dr. Frank S. Holman, Chairman; L. C. Perkins, Chairman of the Seattle Section; and Frank A. Little, Treasurer.

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The eye was man's first instrument of surveillance. Its most unique characteristic is the ability to distinguish moving objects.

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This is an illustration of LFE's interest in radar techniques with continued emphasis on motion detection. Such techniques are having an evolutionary influence on military and industrial systems.

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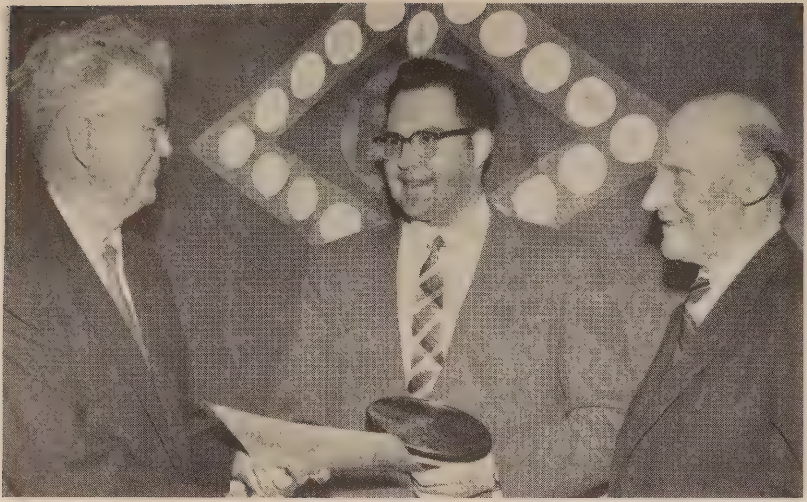


Dr. Edgar A. Sack, Jr. (*center*), who received recognition by Eta Kappa Nu as the outstanding young electrica engineer of 1959, receives congratulations from HKN's President, Albrecht Naeter (*left*) and Dr. Ernst Weber, president of Brooklyn Polytechnic Institute, who delivered the major address of the evening.

optimum operating conditions, g) production control simulation and the comparison of decision rules, and h) manufacturing systems simulation.

The seminar on Statistical Decision-Making is designed for individuals who are engaged in research, experimentation, production, inspection, or acceptance sampling where attention is centered on problems of selecting or ranking processes, methods, or categories according to various criteria of "goodness." It will consist of integrated sessions in which new statistical procedures will be proposed for coping with such multi-decision problems. Among the topics to be discussed will be a) some statistical aspects of experimentation, b) multiple comparison procedures: why and how they are used, c) three-decision problems, d) selection and ranking problems (Bechhofer-Sobel approach), e) selection and ranking problems (Sommerville approach), f) selection and ranking problems (Gupta-Sobel approach), and g) implications of the approaches, directions of research, and new applications.

These seminars are sponsored by the Department of Industrial and Engineering Administration of the Sibley School of Mechanical Engineering, College of Engineering at Cornell. For further information address inquiries to: J. W. Gavett, Seminars Coordinator, Upson Hall, Cornell University, Ithaca, N. Y.

PGPT Calls for Papers

The 4th Annual Conference of the PGPT will be held in Boston, Mass., on November 15–16, in conjunction with the 1960 Northeast Electronics Research and Engineering Meeting (NEREM). Papers for two sessions, to be grouped under the general headings of "Design Techniques That Insure a Better Product," and "Materials and the Product Today," are being solicited. Reports on new and original work in these fields are especially desired. Prospective authors should submit, before June 1, 1960, summaries of their papers, in triplicate, to C. W. Watt, Program Chairman, 4th Annual Conference PGPT, c/o Raytheon Company, Waltham 54, Mass.

Marquette University To Sponsor Institute

An Institute sponsored by the Department of Electrical Engineering of Marquette University will be held on June 1 and 2, 1960. The title of the Institute is "Recent Advances in Solid State Devices." The program emphasizes High-Power Controlled Rectifiers, Application of the Silicon Controlled Rectifier, Parametric Amplification, Tunnel Diode and Applications, Direct Energy Conversion—Thermoelectric Devices, Direct Energy Conversion, Solid State Maser Amplifiers, Avalanche Devices and Solid State "Grown" Circuits. Persons highly specialized in their fields will present the program.

For further information write to Stanley Krupnik, Jr., Assistant Chairman of Electrical Engineering, Marquette University, Milwaukee 3, Wis.

PGRFI Will Conduct 2nd Annual Symposium

The Professional Group on Radio Frequency Interference (PGRFI) will hold its 2nd Annual Symposium in Washington, D. C. at the Shoreham Hotel on June 13 and 14, 1960.

The program will include morning and afternoon sessions on both Monday, June 13 and Tuesday, June 14. The morning session on June 13 will deal with RFI prediction with various computer models, the afternoon program with measurement methods and system characteristics. A total of 10 papers will be presented. The second day will feature a round table discussion in the morning covering the present status of RFI and compatibility standards. In the afternoon, there will be a field trip to the NOL and FCC Laboratories. The ladies' program will include a daily hospitality room, a fashion show, an embassy tea, and a sightseeing tour.

Advance registration is recommended; for further information please contact: E. F. Mischler, Chairman, Public Relations Committee, National Engineering Service, 1108 16th Street, N.W., Washington 6, D.C.

Summer Workshop Announced

A day and a half tutorial program on solid-state electronics is to be presented at Purdue University on June 23 and 24, 1960 under the joint sponsorship of the IRE Professional Group on Education and the Electrical Engineering Division of ASEE. The program for the event was announced by Dr. John G. Truxal and Dr. J. H. Mulligan, Jr., respective Chairmen of the two organizations. Dr. Warren B. Boast, Iowa State University, is Chairman of the Program Committee for the Workshop. Other members are Dr. R. H. Mattson, Iowa State University; Dr. J. L. Moll, Stanford University; Dr. R. L. Pritchard, Texas Instruments, Inc., and Mr. G. R. Madland, Motorola Semiconductor Products Division.

Designed primarily for electrical engineering educators, but open to all interested parties, the Workshop will include nine papers arranged in three sessions as follows:

Thursday afternoon, June 23

"Characteristics of Electrons in Solids," *Dr. J. M. Shive, Bell Telephone Lab., Inc.*

"Semiconductors," *Dr. R. H. Mattson, Iowa State University.*

"Electrical Properties of Semiconductor Materials," *Dr. W. G. Dow, University of Michigan.*

Friday morning, June, 24

"Diodes," *Dr. M. O. Thurston, Ohio State University.*

"Transistors," *Dr. J. M. Early, Bell Telephone Lab., Inc.*

Friday afternoon, June 24

"Energy Conversion Devices," *Dr. S. J. Angello, Westinghouse Electric Corp.*

"Low Temperature Devices," *Dr. A. L. McWhorter, Lincoln Labs., M.I.T.*

"Other Solid State Devices," *Dr. J. L. Moll, Stanford University.*

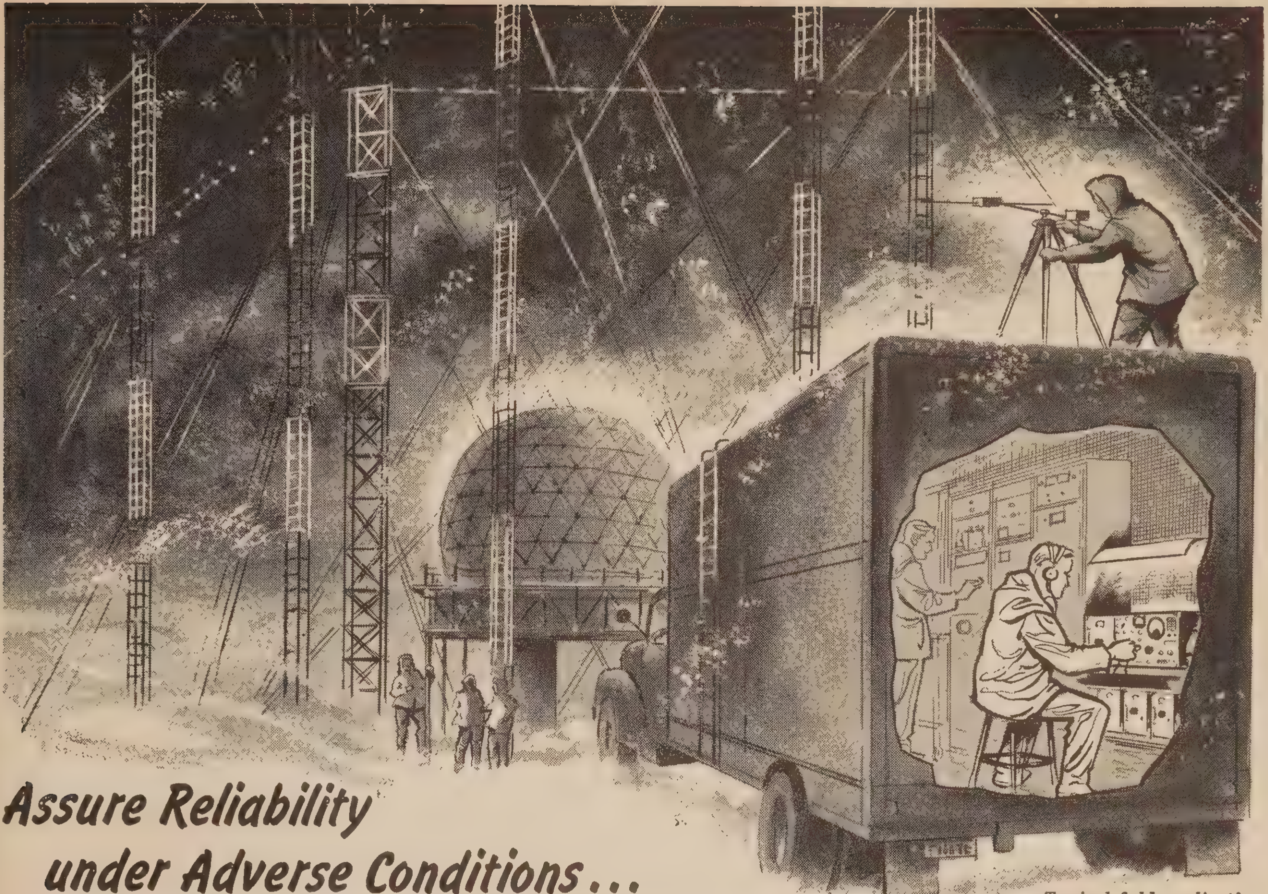
Further details regarding program information may be obtained from Dr. Warren B. Boast, Iowa State University, Ames, Iowa; information regarding living accommodations for the meeting may be obtained from Dr. Thomas F. Jones, Purdue University, Lafayette, Ind.

The Workshop on Solid-State Electronics is but one of the events of the Electrical Engineering Division scheduled for the ASEE Annual Meeting at Purdue University. On Monday, June 20 there will be a session on "Learning Machines" under the chairmanship of Professor A. V. Eastman of the University of Washington. The following papers will be presented:

"The Automization of Socrates," *Dr. D. Cook, Purdue University.*

"Design Techniques of Automatic Teaching Machines," *Dr. H. A. Baldwin, University of Arizona.*

"Teaching Elementary Stress Analysis



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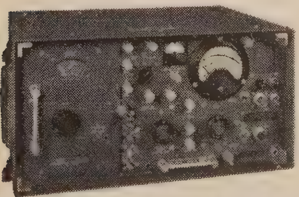

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MISCELLANEOUS IRE PUBLICATIONS AVAILABLE

The following issues of miscellaneous publications are available from the Institute of Radio Engineers, Inc., 1 East 79th Street, New York 21, New York, at the prices indicated below:

Meetings	Publications	Price per Copy
Aeronautical and Navigational Electronics Conference	*Proceedings of the 5th Annual East Coast ANE Conference,* held October 27-28, 1958 in Baltimore, Md.	$5.00*
Electronic Components Symposium	*Proceedings of the 1957 Electronic Components Symposium,* held May 1-3, 1957 in Chicago, Ill.	5.00
Electronic Computer Conferences	*Proceedings of the Joint AIEE IRE ACM Eastern Conference,* held December 10-12, 1951 in Philadelphia, Pa.	3.50
	Proceedings of the Joint AIEE IRE ACM Eastern Conference, held December 8-10, 1954 in Philadelphia, Pa.	3.00
	Proceedings of the Joint AIEE IRE ACM Eastern Conference, held November 7-9, 1955 in Boston, Mass.	3.00
	Proceedings of the Joint AIEE IRE ACM Eastern Conference, held December 10-12, 1956 in New York, N. Y.	3.00
	Proceedings of the Joint AIEE IRE ACM Eastern Conference, held December 9-13, 1957 in Washington, D. C.	3.00
	Proceedings of the Joint AIEE IRE ACM Eastern Conference, held December 3-5, 1958 in Philadelphia, Pa.	3.00
	Proceedings of the Joint AIEE IRE ACM Eastern Conference, held December 1-3, 1959 in Boston, Mass.	3.00
	Proceedings of the Joint AIEE IRE ACM Western Conference, held March 1-3, 1955 in Los Angeles, Calif.	3.00
	Proceedings of the Joint AIEE IRE ACM Western Conference, held February 7-9, 1956 in San Francisco, Calif.	3.00
	Proceedings of the Joint AIEE IRE ACM Western Conference, held May 6-8, 1958 in Los Angeles, Calif.	4.00
	Proceedings of the Joint AIEE IRE ACM Western Conference, held March 3-5, 1959 in San Francisco, Calif.	6.00
Magnetic Amplifiers Conference	*Proceedings of the Conference on Magnetic Amplifiers,* held April 5-6, 1956 in Syracuse, N. Y.	4.00
Bio-Medical Electronics Bibliographies	*Bibliography on Medical Electronics,* June 1958 *Bibliography on Medical Electronics,* June 1959 (Supplement #1)	2.50 2.50
Military Electronics	*Proceedings of the 1st National Convention,* held June 17-19, 1957 in Washington, D. C.	5.00†
	Proceedings of the 2nd National Convention, held June 16-18, 1958 in Washington, D. C.	5.00†
	Proceedings of the 3rd National Convention, held June 29-July 1, 1959 in Washington, D. C.	4.00
Reliability and Quality Control in Electronics Symposia	*Proceedings of the 4th National Symposium,* held January 6-8, 1958 in Washington, D. C.	5.00
	Proceedings of the 5th National Symposium, held January 12-14, 1959 in Philadelphia, Pa.	5.00
	Proceedings of the 6th National Symposium, held January 11-13, 1960 in Washington, D. C.	5.00
Telemetering Conference and Symposia	*Proceedings of the 1953 National Conference,* held May 20-22, 1953 in Chicago, Ill.	2.00
	Proceedings of the 1958 National Symposium, held September 22-24, 1958 in Miami Beach, Fla.	5.00
	Proceedings of the 1959 National Symposium, held Septemper 28-30, 1959 in San Francisco, Calif.	5.00

* IRE Member Rate $3.50.
† IRE Member Rate $3.00.

by Machine," *Dr. A. F. Johnson and Dr. D. J. Mayhew, University of Utah.*

"MARI—A Simple Electrical Teaching Device," *Dr. M. Crosby and Dr. O. Lancaster, Pennsylvania State University.*

On Monday evening at 8:00 P.M. there will be a panel discussion on the theme "The Role of the Electrical Engineering Division in the Next Decade." Participants will be Dr. Warren B. Boast, Head, Electrical Engineering Department, Iowa State University; Dr. Richard K. Moore, Head, Electrical Engineering Department, University of New Mexico; and Dr. James H. Mulligan. Jr., Head, Electrical Engineering Department, New York University.

On Tuesday, June 21 at 2:00 P.M. there will be a session devoted to Probability and Statistics in Electrical Engineering under the direction of Dr. J. Stuart Johnson, Dean of Engineering, Wayne State University. The four papers scheduled for this meeting are:

"Mathematics Approach to Probability and Statistics Instruction for Electrical Engineers," *Dr. J. G. Brainerd, University of Pennsylvania.*

"Electrical Engineering Approach to Probability and Statistics Instruction for Electrical Engineers," *Dr. R. J. Schwarz, Columbia University.*

"Random Process Studies and Information Theory," *Dr. V. C. Rideout and Dr. A. Burr, University of Wisconsin.*

"Reliability of Electronic Equipment," *Dr. C. A. Krohn, Motorola, Inc.*

PHOTOGRAPHY SEMINAR TO BE HELD AT M.I.T.

The scientific and engineering uses of high-speed photographic measurement techniques will be the subject of a one week seminar at the Massachusetts Institute of Technology, starting Monday, August 15, 1960. The meetings will center at the Stroboscopic Light Laboratory where the theory and application of numerous methods will be discussed and studied.

It is planned that mornings will be devoted to theory and demonstrations and the afternoons to laboratory practice and experience.

Subjects to be covered include pulsed stroboscopic lighting, optical high-speed cameras, Kerr cells, Faraday shutters, image converters, and so forth. Specialists in high-speed photography have been invited to cover their subjects at the seminar, and there will be practical laboratory demonstrations of many types of high-speed photography equipment.

The high-speed motion picture and still cameras give space-time resolution for complicated mechanical motions. In some ways one can think of high-speed cameras as instruments for the mechanical engineer that correspond to the cathode-ray oscillograph for the electrical. One of the objects of the seminar is to give those who attend a real working knowledge of the various devices.

The program is under the direction of Professor Harold E. Edgerton of the Department of Electrical Engineering at M.I.T. For further information inquire from the Office of the Summer Session, Room, 7-103, M.I.T., Cambridge 39, Mass.

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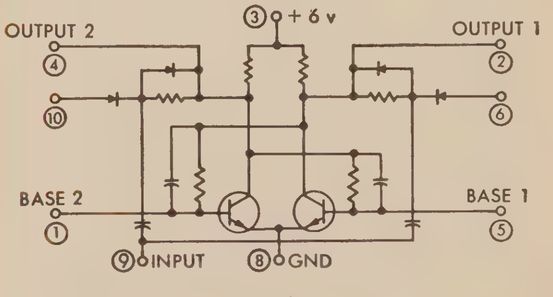

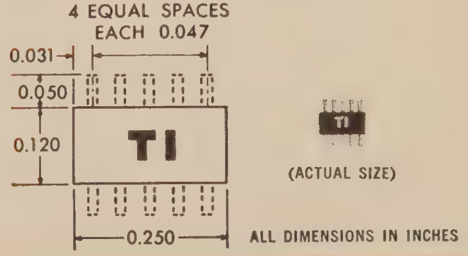

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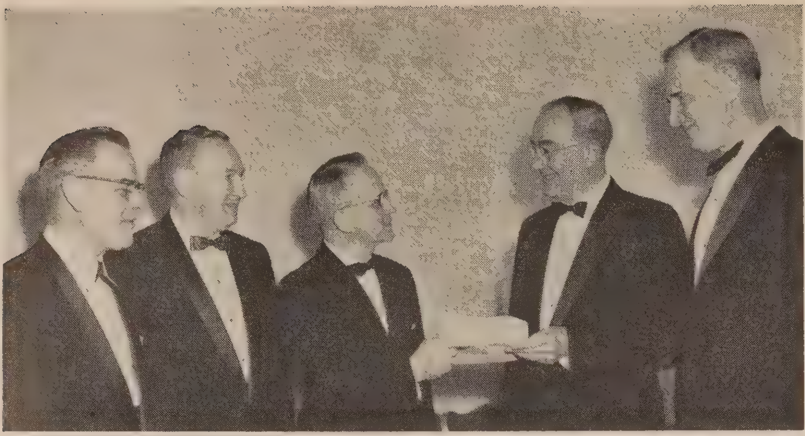

Three members of the Washington, D. C., Section received Patron Awards for "distinguished service" to the Section at the Annual Banquet on February 13, 1960. *Left to right:* Stuart L. Bailey, President, Jansky and Bailey; Leland D. Whitelock, Head Engineer, Communications Branch, Bureau of Ships, Navy Department; John Durkovic, Chairman, Washington Section; Frencis H. Engel, Assistant to the Vice President, RCA Defense Electronics; and Dr. Ronald L. MacFarlan, IRE President, 1960.

RECORD ATTENDANCE AT 1960 SOLID-STATE CIRCUITS CONFERENCE

Over 3000 attended the recent 1960 International Solid-State Circuits Conference which was held on the campus of the University of Pennsylvania and at the Sheraton Hotel in Philadelphia, Pa.

Among those in attendance were scores of solid-state specialists from abroad—Japan, Italy, France, Sweden, Hungary, Switzerland, England and the Netherlands.

Honored guests included Leo Esaki of tunnel-diode fame; M. J. O. Strutt, chairman, Electrical Engineering Department, Swiss Federal Institute of Technology, and C. Guy Suits, Vice President and Director of Research, General Electric Company, the latter delivering invited addresses at the formal opening of the meeting.

A tribute was paid to the late Dudley Buck during an afternoon memorial session.

A complete conference report—100-page-letterpress-book with over 300 illustrations—covering the 43 papers presented, was distributed to all registrants. Post-conference copies of this text, officially known as the Digest of Technical Papers, are available from Henry G. Sparks, Moore School of Electrical Engineering, University of Pennsylvania, Philadelphia 4, Pa., at $5.00 per copy. Remittance to be made out to "Solid-State Circuits Conference."

PURDUE UNIVERSITY TO HOST ANNUAL CONVENTION ON ENGINEERING EDUCATION

The fact that engineering education is currently in a state of change is reflected in the program which the American Society for Engineering Education has planned for its 68th annual convention at Purdue University June 20 through 24, 1960.

This largest and most significant meeting of the year, between educators and the engineers and employers of engineers in industry, will begin with an address by President Frederick L. Hovde of Purdue on his philosophy of the total education of the engineer. Some 45 general sessions and special conferences will follow during the week, in addition to numerous luncheons, dinners, and entertainment features.

Sessions will be held on "Methods of Teaching Electrical Engineering," "The Impact of Digital Computers on Engineering Education," and the EE and IRE Divisions will hold an extended workshop on "Solid State Electronics."

Of special note will be a general session by the Relations With Industry Division on Wednesday, June 22, on "Long Range Education and Development of the Engineer." Addresses will be given by Dr. Carl W. Borgmann, of the Ford Foundation; P. E. Haggerty, president of the Texas Instrument Company; Will Mitchell, Jr., associate research director of Allis Chalmers; and E. C. Koerper, consulting engineer.

A joint session by the Aeronautical Engineering, Mathematics and Physics Divisions will have as its theme "The Impact of New Technologies."

The currently live topic of high school preparation for college will be the subject of a major session to be presided over by Dr. A. R. Spalding, head of the Purdue department of freshman engineering, which receives some 2000 freshmen from secondary schools each year.

The Mechanics Division will feature a critical examination of "Substance and Objectives of Typical Curricula in Engineering Mechanics, Engineering Science, and Engineering Physics" by a panel consisting of Dr. Fred Lindvall, chairman of engineering at California Institute of Technology; Dr. Paul Chenea, head of the School of Mechanical Engineering at Purdue; Dr. J. H. Meier of General Electric; and Dr. Charles E. Taylor, of the University of Illinois.

Other major topics include "An Evaluation of Cooperative Education," "A National Survey of Technical Institute Education," and "The Future of Industrial Engineering."

For reservations and a complete program, address Prof. Mark Roberts, Engineering Administration, Purdue University, Lafayette, Ind.

TELEMETERING CONFERENCE PROGRAM COMPLETED

The 1960 National Telemetering Conference will be held May 23–25, 1960 at the new Miramar Hotel in Santa Monica, Calif. The theme of this year's conference is "Telemetry—Tool for Industry and Defense." Sponsoring societies are the Instrument Society of America (ISA) which is the 1960 host, the American Rocket Society (ARS), the American Institute of Electrical Engineers (AIEE), the Institute of Aeronautical Sciences (IAS), and the Institute of Radio Engineers (IRE).

Seventy-one technical papers have been selected, and will be presented in panel form in 16 separate sessions running 3 sessions concurrently. In addition, two workshop sessions are scheduled. Session topics are:

Monday Morning, May 23

"Industrial Data Transmission Systems"
"Bio-Medical Measurements"
"Space Data Acquisiton Systems"

Monday Afternoon

"General RF Components and Techniques"
Missiles and Aircraft Telemetry Workshop—
"R&D Needed in the 60's"
"Data Processing and Presentation"—I

Tuesday Morning, May 24

"PCM Progress"
"General—Transducers"
"Ground Stations—New Components and Techniques"

Tuesday Afternoon

"Industrial Supervisory Control"
"Missiles and Aircraft—Flight Data Systems"
"Telemetry Techniques"—I

Wednesday Morning, May 25

"Data Processing and Presentation"—II
"Missiles and Aircraft—Environment Measurement"
"General Transistorization Progress"

Wednesday Afternoon

Industrial Telemetry Workshop—"What We Really Need Is . . . "
"Telemetry Techniques"—II
"Reliability in Telemetry"

The latest in telemetry equipment and techniques will be displayed by leading manmanufacturers for both commercial industry and the military. Over 66 exhibit booth spaces have been provided in a layout in two large halls which are near to the technical sessions. In addition to the banquet and cocktail party, several interesting tours are planned for both conferees and wives.

Additional information may be obtained by contacting the Conference Chairman, Hugh Pruss, 8345 Hayvenhurst Ave., Sepulveda, Calif.

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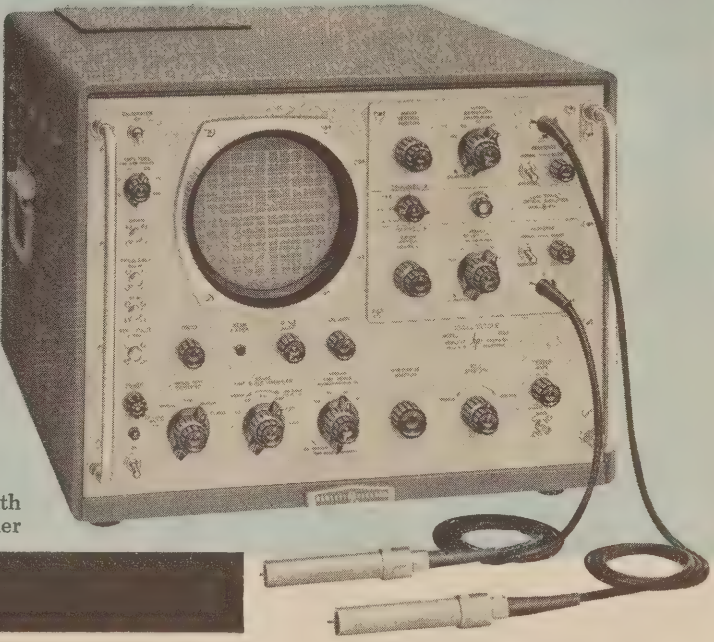

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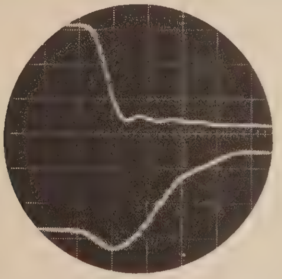

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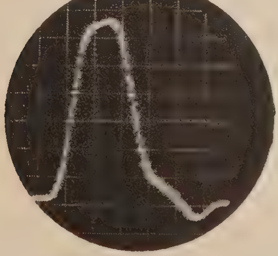

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hp *over 300 fast, accurate measuring instruments* and development—are invited for presentation at the 1960 Northeast Electronics Research and Engineering Meeting (NEREM) which will be held on November 15, 16, 17, 1960, in the Commonwealth Armory and the Sheraton-Plaza Hotel, Boston, Mass.

This year's meeting will project a marked departure in technical program format, scope and size, as well as type and number of exhibits. The program will feature many invited state-of-the-art tutorial sessions, with related evening informal discussion periods.

All registrants will receive, free-of-additional charge, a copy of the NEREM Record, a printed 200-page conference report with 600–1000 word digests (supported by drawings and photographs) of every paper presented at the meeting. Illustrated profiles of every NEREM speaker will also be included in the Record.

A suggestive, but not inclusive, list of subject areas for NEREM 1960 is: Antennas; Circuit Theory; Components, Production Techniques and Reliability; Electronic Computers; Engineering Management; Feedback Control Systems; Information Theory and Processing; Biomedical Electronics; Microwave Devices—Theory and Techniques—Involving Ferrites, Masers, Parametric Amplifiers and Ionized Media; Military Electronics Including Inertial, Infrared and Data-Handling Systems; Semiconductor Devices and Circuits Including Micro-Circuitry and Photo Electronic Applications.

To permit the development of well-integrated technical sessions, speakers are requested to furnish either complete papers or 400–500 word abstracts, in triplicate, plus 50-word summaries for advance program mailings.

All material should be mailed on or before July 15, 1960 to the 1960 NEREM Program Chairman, J. H. Mulligan, Jr., Dept. of Electrical Engineering, New York University, New York 53, N. Y. Authors will be notified of paper acceptance or rejection by August 15, 1960.

1922 receiver demonstrated at IRE Section Annual Banquet—The operation of the "Aeriola Sr. Receiver," a Westinghouse Product, is demonstrated by Captain W. F. Kirlin, Chairman of the Northwest Florida Section of the IRE, to Dr. R. L. McFarlan, International President of the IRE, and General R. H. Warren, Vice Commander, APGC. Ralph Coe, (left) Section Vice-Chairman, and Harold Hufnagle (right), Section Secretary-Treasurer, look on.

May Schedule Planned By Air Force MARS

The following is the schedule of the Air Force MARS Eastern Technical Net (3295 kc, 7540 kc, and 15,715 kc, on Sundays from 2 to 4 P.M. EST):

May 1 "Quality Control Techniques," A. Stein, Statistical Engineer, Riverside Plastics Corp.

May 8 "Medical Electronics in Gastro-Intestinal Research," Dr. J. T. Farrar, Chief, Gastro-Neurology Section of the Veterans' Hospital of New York and R. Bostrom, Research Engineer, Airborne Instruments Lab.

May 15 "The Evolution of Modern Radar," Dr. N. J. Nilsson, Chief, Directorate of Control and Guidance, Advanced Developments Lab., Rome Air Development Center, USAF.

May 22 "Air Crew Escape Systems," Discussion by engineers from Frankford Arsenal, USA.

May 29 "Materials," Discussion by engineers from Frankford Arsenal, USA.

1960 IRE 7th Region Conference

OLYMPIC HOTEL, SEATTLE WASH., MAY 24–26, 1960

The cocktail party, to be held May 24 in the Olympic Hotel, Seattle, Wash., is the traditional opening of the IRE 7th Regional Conference. The All-Industry Luncheon will also be held on May 24, in the Spanish Ballroom of the Olympic Hotel.

On May 25 a field trip will be conducted to the Transport Division of the Boeing Airplane Company, Renton, Wash. This will provide views of the following: the factory, flight line (radar test), electronic shops (radar checkout), electronic mock-up landing simulator, computer—IBM 704 (evaluation of flight situations), and airplane mock-up, both present and future.

Women's activities, under the direction of Mrs. Frank S. Holman, will include a reception and several cruises and excursions to interesting sites in the area.

Session 1—Opening General Session

Tuesday Morning, May 24

Chairman: *O. G. Villard, Jr., Stanford Univ., Stanford, Calif.*

Speakers: *F. S. Holman, Chairman, 7th Region Conference, Boeing Airplane Co., Seattle, Wash.; R. L. McFarlan, President, IRE; R. N. Clark, Univ. of Washington, Seattle; O. G. Villard, Jr., Stanford Univ., Stanford, Calif.*

Session 2

Control Systems I—Performance Criteria

Tuesday Afternoon

Chairman: *G. F. Franklin, Stanford Univ., Stanford, Calif.*

Co-Chairman: *F. C. Fickeisen, Boeing Airplane Co., Seattle, Wash.*

"Optimum Performance Criteria with a Minimum Lead System," *G. S. Axelby. Westinghouse Corp., Baltimore, Md.*

"Consideration in the Design of Feedback Control Systems with Optimum Performance," *R. L. Cosgriff and E. J. Hagin, Ohio State Univ., Columbus.*

"Optimum Control System with Minimum Spectral Bandwidth," *J. C. Hung, New York Univ., New York, N. Y.*

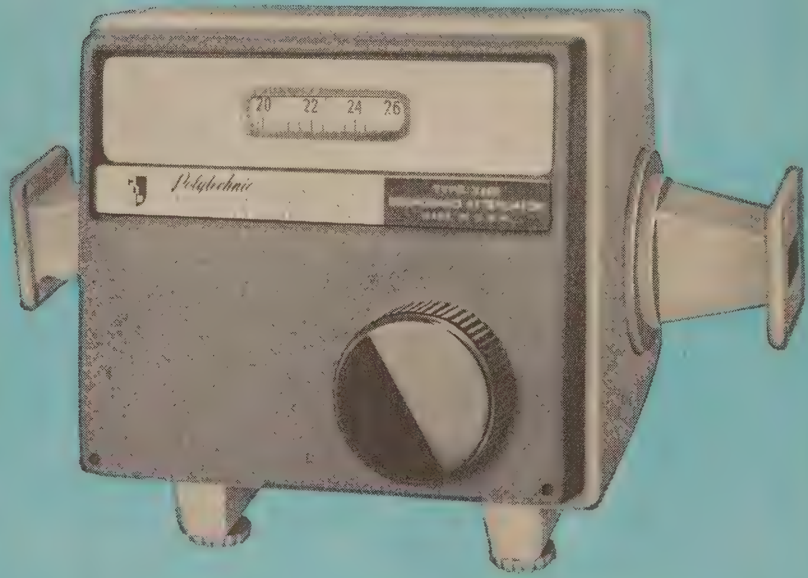
"Performance Measures—Past, Present, and Future," *W. C. Schultz, Cornell Aero Lab., Buffalo, N. Y., and V. C. Rideout, Univ. of Wisconsin, Madison.*

Session 3

Solid State Electronics I—Semiconductors

"Negative Resistance Processes in Semiconductors," *R. E. Burgess, University of*

PRD's brand new Broadband Attenuators



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Attenuation Range: 60 db

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H 101	7.05 — 10.0	0.5 db	11⅜	6 5/16	7 3/16
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U 101	12.4 — 18.0	0.7 db	7 11/16	5⅛	6¼
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British Columbia, Vancouver, Canada.

"Recent Progress in the Development of High Frequency Transistors," *G. N. Hanson, Bell Telephone Labs., Allentown, Pa.*

"Some Aspects of Semiconductor Noise," *A. Van Der Ziel, Univ. of Minnesota, Minneapolis.*

"Maser Operation at Infrared and Optical Frequencies," *L. C. Levitt, Hughes Research Labs., Culver City, Calif.*

Session 4

Control Systems II—Optimal Design Techniques

Wednesday Morning, May 25

Chairman: *A. H. Koschmann, Univ. of New Mexico, Albuquerque.*

Co-Chairman: *R. M. Hubbard, Boeing Airplane Co., Seattle, Wash.*

"Performance Criteria in Adaptive Control," *C. W. Sarture and J. A. Aseltine, Space Technology Labs., Los Angeles, Calif.*

"Limit Cycle Efficiency of On-Off Reaction Control Systems," *G. W. Freeman, Boeing Airplane Co., Seattle, Wash.*

"Design Aspects of Attitude Control Systems," *M. F. Marx, General Electric Co., Schenectady, N. Y.*

"A Simulator Study of a Two-Parameter Adaptive System," *V. C. Rideout and R. J. McGrath, Univ. of Wisconsin, Madison.*

Session 5

Solid State Electronics II—Solid State Energy Conversion

Session 6

Electromagnetics I—Radio Astronomy

"Radio Emission from the Sun at Decametric Wavelengths," *J. W. Warwick, High Altitude Observatory Univ. of Colorado, Boulder.*

B. S. Yaplee, *Radio Astronomy Br., U. S. Naval Research Lab., Washington, D. C.*

D. D. Cudaback, *Electrical Engineering Dept. Stanford Univ., Stanford, Calif.*

A. E. Lilley, *Harvard College Observatory, Cambridge, Mass.*

Session 7

Control Systems III—Nonlinear and Sampled Data Systems

Wednesday Afternoon

Chairman: *R. E. Hanna, Douglas Aircraft Co., Santa Monica, Calif.*

Co-Chairman: *E. Noges, Univ. of Washington, Seattle.*

"Nonlinear Effects in Servo Control Systems," *R. B. Higley, Autonetics, Downey, Calif.*

"Control of Higher Order Systems Based on Time Optional Regulations," *F. B. Smith, Minneapolis Honeywell, Minneapolis, Minn.*

"An Error Minimization Technique for Sampled-Data Systems," *A. F. Engelbrecht and C. W. Steeg, Jr., Radio Corporation of America, Burlington, Mass.*

Session 8

Electromagnetics II—Very Large Aperture Antennas

"Radar Astronomy: A New Technique for the Study of the Solar System," *R. L. Leadabrand and R. B. Dyce, Stanford Research Inst., Menlo Park, Calif.*

"The Design and Operation of a Two-Mile Aperture Antenna," *W. C. Erickson, Convair Scientific Research Lab., San Diego, Calif.*

"Environmental Antenna Patterns," *J. F. Carpenter, Dalmo Victor Co., Division of Textron, Inc., Belmont, Calif.*

"The Ohio State 360 Foot Radio Telescope," *R. T. Nash, Radio Observatory, Dept. of Electrical Engineering, Ohio State Univ., Columbus.*

Session 9

Student Prize Paper Contest—IRE 7th Region Finals

Wednesday Evening

Chairman: *F. D. Robbins, Univ. of Washington, Seattle.*

Session 10

Engineering Management Symposium—Technical Management of Large Systems

Session 11

Control Systems IV—Biological Control Systems

Thursday Morning, May 26

"The Design of Man-Machine Systems by Means of Quantitative Analysis Techniques of Human Factors Engineering," *O. H. Lindquist, Minneapolis-Honeywell, Minneapolis, Minn.*

"Control Systems Characteristics of the Respiratory System," *A. C. Young, Univ. of Washington, Seattle.*

"Relaxation and Transit Time Oscillations in the Heart," *J. W. Woodbury, Univ. of Washington, Seattle.*

Session 12

Electromagnetics III—Arctic Ionospheric Phenomena

"Distribution of Auroral Radar Disturbances in Alaska During the IGY," *R. S. Leonard, Geophysical Inst., College, Alaska.*

"Sweep-Frequency Backscatter Studies in the Auroral Zone," *H. F. Bates, Geophysical Inst., College, Alaska.*

"High Frequency Studies of the Arctic Ionosphere," *L. Owren and R. D. Hunsucker, Geophysical Inst., College, Alaska.*

"A High Latitude Study of Spread F Echoes," *Z. A. Ansari and L. Owren, Geophysical Inst., College, Alaska.*

Session 13

Solid State Electronics III—Magnetics and Dielectrics

Thursday Afternoon

"Ferroelectric Power Converters," *S. R. Hoh, IT and T Co., Nutley, N. J.*

"New Magnetic Devices for Digital Computers," *D. H. Looney, Bell Telephone Labs., Murray Hill, N. J.*

L. Rimai, Raytheon Co., Waltham, Mass

Session 14

Electromagnetics IV—Terrestrial Electromagnetic Effects

"Terrestrial Propagation of VLF Radio Waves," *J. R. Wait, National Bureau of Standards, Boulder, Colo.*

"Whistlers and Related Phenomena," *R. A. Helliwell, Radioscience Lab., Stanford Univ., Stanford, Calif.*

"Effects of Terrestrial Electromagnetic Disturbances on Wireline Communications," *R. Sanders, Hughes Aircraft Co., Culver City, Calif.*

"Fading of Radio Waves Vertically Incident Upon the Ionosphere," *D. H. Schrader and H. M. Swarm, Dept. of Electrical Engineering, Univ. of Washington, Seattle.*

Fourth National Convention on Military Electronics

SHERATON PARK HOTEL, WASHINGTON, D.C., JUNE 27–29, 1960

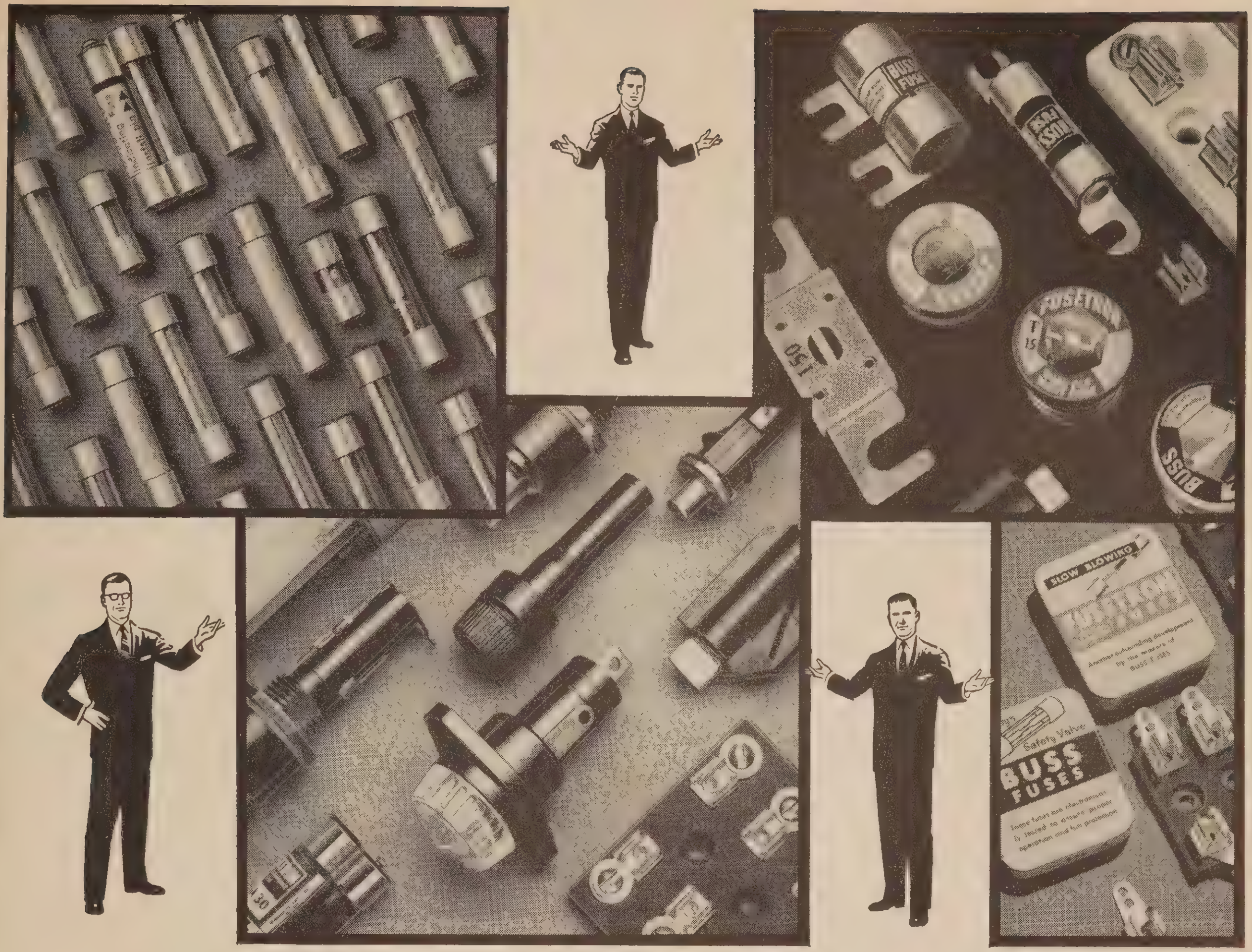
A panel discussion on military research and development will highlight the opening session of the 4th National Convention on Military Electronics (MIL-E-CON 1960) which will be held again this year in Washington, D.C. on June 27–29. This annual meeting is sponsored by the Professional Group on Military Electronics.

Dr. Jerrold R. Zacharias, Professor of Physics at the Massachusetts Institute of Technology, will moderate the discussion by officers from the three military services, including Vice Admiral John T. Hayward, USN, Deputy Chief of Naval Operations (Development) and Major General Leighton I. Davis, USAF, Assistant Deputy Chief of Staff, Development, U.S. Air Force.

The technical program includes 25 sessions, 20 of which will be unclassified. The Air Force Research and Development Command will sponsor five classified sessions at MIL-E-CON 1960; security clearance is required for attendance at these classified meetings. Printed copies of the 1960 *Conference Proceedings*, containing the unclassified papers, will be distributed free of charge to each registrant.

Exhibits of the latest in military components and equipment will fill the exhibit areas of the Sheraton-Park Hotel. The exhibits will run concurrently with the technical sessions.

On the social side, there will be a Keynote Luncheon on Monday, June 27, a buffet and entertainment Monday evening, a Ladies' Breakfast on Tuesday, and the An-



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nual Banquet Tuesday evening, featuring a prominent guest speaker and the presentation of the Barry M. Carlton Award. The Washington Chapter of PGMIL will be the host at the Keynote Luncheon, with Major General Earle F. Cook, USA, Deputy Chief Signal Officer, as the speaker. Dr. Edward G. Witting, Deputy Director of Research and Development, Office of the Secretary of the Army, and chairman of the Washington Chapter, PGMIL will be the master of ceremonies at this luncheon. A meeting of the Administrative Committee of PGMIL is scheduled for Tuesday morning.

Advance registration fees, which include the *Conference Proceedings*, are $2 for IRE members, $3 for nonmembers, and $1 for students. Deadline for advance registration is June 1. At-the-door registration fees will be $4 for IRE members, $5 for nonmembers, and $1 for students. Tickets for the luncheon are $3.50; for the Ladies' Day Breakfast, $2; for the buffet $5; and for the banquet, $10. Tables seating eight may be reserved for the banquet at $80 each. Mr. Jack Carter, Jansky & Bailey, Inc., 3269 M Street, N. W., Washington 7, D.C., is chairman of the Registration Committee.

Robert H. Cranshaw, Manager, Advanced Space Products, General Electric Company, Utica, New York, is President of MIL-E-CON 1960. Dr. Craig M. Crenshaw, Chief Scientist, Office of the Chief Signal Officer, Department of Defense (Army), is Chairman of the Technical Program Committee.

Monday Afternoon, June 27

Session 1.1—Reconnaissance and Ranging I (Confidential)

Sponsor: Air Research and Development Command.

Moderator: *To be announced.*

"Experimental Evaluation of a Diversity Radar," *P. W. Crist, Airborne Instruments Lab., Melville, N. Y.*

"Radar Density Related to Tactical Troop Concentrations," *R. T. Stefancik, G. C. Arrowsmith, and G. A. Pitsenbarger, Sylvania Electronic Defense Lab., Mountain View, Calif.*

"Instrumentation System for Three-Dimensional Tracking of Underwater Missiles," *C. S. Soliozy and J. M. Formwalt, U. S. Naval Underwater Ordnance Station, Newport, R.I.*

"ITT Secure Ranging and Communication System," *A. E. Nashman, ITT Labs., Nutley, N. J.*

"Identification and Evaluation of Magnetic Field Sources Associated with Magnetic-Anomaly Detector Equipped Aircraft," *P. Leliak, The Martin Co., Baltimore, Md.*

"Inertialess Scanning and Tracking Radar (INSTAR)," *J. R. Karp, The W. L. Maxson Corp., New York, N. Y.*

Session 1.2—Satellite Electronics

Moderator: *To be announced.*

"A Satellite Microwave Telemetry Oscillator Using Traveling-Wave Tube Techniques," *L. A. Roberts, Watkins-Johnson Co., Palo Alto, Calif.*

"Application of Microminiaturization Concepts to Space Guidance Computers," *E. Keonjiam, American Bosch Arma Corp., Hempstead, N. Y.*

"Criteria for the Optimum Design of Active Satellite Communication Systems," *A. R. Giddis, Philco Western Development Lab., Palo Alto, Calif.*

"Satellite Ionosounder," *S. Horowitz, AF Cambridge Research Center, Bedford, Mass., and L. Humphrey, General Electric Co., Ithaca, N. Y.*

"Satellite Reliability Achieved Through Comprehensive Environmental and Functional Testing," *J. A. Chambers, U. S. Army Ordnance Missile Command, Redstone Arsenal, Ala.*

"A Compact UHF Diplexer for Applications Involving Rockets or Satellites," *S. E. Parker, Hughes Aircraft Co., Culver City, Calif.*

Session 1.3—Microwave Devices and Techniques

Moderator: *G. R. Kilgore, Westinghouse Electric Corp., Baltimore, Md.*

"Status of Ultra-Low-Noise Traveling-Wave Tubes and Beam-Type Parametric Amplifiers," *K. Kotzebue, B. P. Israelsen and G. E. St. John, Watkins-Johnson Co., Palo Alto, Calif.*

"New Microwave Devices with Bulk Semiconductors," *H. Jacobs, F. A. Brand, M. Benanti, J. Meindl, and R. Benjamin.*

"Phase Stable Limiting Amplifiers Using Beam Deflection Tubes," *E. R. Wingrove, Jr., General Electric Co., Syracuse, N. Y.*

"Applications of Traveling Wave Tubes to Microwave Circuits," *G. E. Austin, Sylvania Electronic Defense Lab., Mountain View, Calif.*

"Recent Electronic Scanning Developments," *J. P. Shelton and K. S. Kelleher, Aero Geo Astro Corp., Alexandria, Va.*

"Practical Stripline Component Design," *V. T. Norwood, Hughes Aircraft Co., Culver City, Calif.*

Session 1.4—Instrumentation

Moderator: *To be announced.*

"The Pulsed Light Theodolite," *L. A. Jay, U. S. Army Electronic Proving Ground, Fort Huachuca, Ariz.*

"Multiple High-PRF Ranging," *D. H. Mooney and W. A. Skillman, Westinghouse Electric Corp., Baltimore, Md.*

"Recent Achievements in Missile-Borne Magnetic Tape Recorders," *M. M. Siera, Lockheed Aircraft Corp., Palo Alto, Calif.*

"Hit Indicator Techniques for Direct Fire Weapons," *H. Chaskin, U. S. Naval Training Device Center, Port Washington, N. Y.*

"Effects of Atmospheric Pollutants on Electronic Equipment." *H. C. McKee, Southwest Research Inst., San Antonio, Texas.*

"A Delay-Line Synthesized Filter Bank with Electronically Adjustable Impulsive Response," *H. J. Bickel and E. Brookner, Federal Scientific Corp., New York, N. Y.*

Session 1.5—Noise Effects on Precision and Data

Moderator: *To be announced.*

"0.1% Accuracy Variable Speed Control System," *M. Hartman, Fairchild Camera and Instrument Corp., Syosset, L. I., N. Y.*

"Pulse Operation of DC Servo Motors for Lower Thresholds," *D. J. Salonimer and W. E. Yoakum, Guided Missile Agency, Redstone Arsenal, Ala.*

"A Mathematical Analysis of Transients Caused by AGC Reset in Line Switching Amplifier as Used in AN/MSQ-18 (Missile Monitor) Equipment," *1st. Lt. R. A. Perry and SP-4 J. M. Dugan, U. S. Army Air Defense Board, Fort Bliss, Texas.*

"An Analogue Computer for Separating Evoked Physiological Potentials from Background Noise," *W. Korpfl, R. Robinson and J. C. Armington, Walter Reed Army Inst. of Res., Washington, D. C.*

"Precision Frequency Measurement of Noisy Doppler Signals," *W. A. Dean, Ballistic Measurements Lab., Aberdeen Proving Ground, Md.*

"Output Signal-to-Noise Characteristics of Correlators," *B. R. Mayo and D. K. Cheng, General Electric Co., Syracuse, N. Y.*

Tuesday Morning, June 28

Session 2.1—Communications and Data Handling (Confidential)

Sponsor: Air Research and Development Command.

Moderator: *F. Brady, Research and Development Div., Office of The Chief Signal Officer, Dept. of the Army, Washington, D. C.*

"Engineering Analysis of Qualitative Data to Provide a Missile System for Simulation and Vulnerability Studies," *N. Johnson, Sylvania Electronic Defense Lab., Mountain View, Calif.*

"Spasur Automatic Digital Data Assembly System, Part I—The Digital Data Transmission Problem, Part II—Description of the Digital System," *W. B. Poland, Jr., U. S. Naval Research Lab. and M. S. Maxwell, and J. Pinker, U. S. Naval Weapons Lab., Dahlgren, Va.*

"Simulation by Interpretation," *F. W. Sinn, Jr. and J. J. Wolf, Burroughs Corp., New York, N. Y.*

"A Transistorized Digital Range Unit," *R. M. Lucas, Bell Telephone Labs., Inc., Whippany, N. J.*

"Pacific Missile Range Communications," *S. H. Vogt, Dept. of the Navy, Washington, D. C.*

"Evaluation of Video and IF MTI Cancellation Techniques," *E. C. Nordell, General Electric Co., Dewitt, N. Y.*

Session 2.2—Communications I

Moderator: *To be announced.*

"Military Applications for Speech Compression Techniques," *A. J. Strassman, Hughes Aircraft Co., Los Angeles, Calif.*

"Instrumentation Used for Ionosphere Electron Density Measurements," *W. J. Cruickshank, Ballistic Research Lab., Aberdeen Proving Ground, Md.*

"Electron Density Measurements in Hypersonic Projectile Trails," *R. S. Hebbert, U. S. Naval Ordnance Lab., White Oak, Silver Spring, Md.*

"Topology Engineering of Communication Networks," *Dr. K. Ikrath and C. C. Comstock, Hqs. U. S. Army Signal Res. and Dev. Lab., Fort Monmouth, N. J.*

"Frequency Selection," *H. R. Smith, Sierra Vista, Ariz.*

"The Economic Design of Radio Communication Systems by Matching the Message Urgency to the Fading Conditions," *L. P. Yeh, Page Communications Engineers, Inc., Washington, D. C.*

Session 2.3—Reliability

Moderator: *To be announced.*

"Serviceability: Complement to Reliability," *R. H. Wilcox and Cdr. V. R. Wanner, Office of Naval Res., Washington, D. C.*

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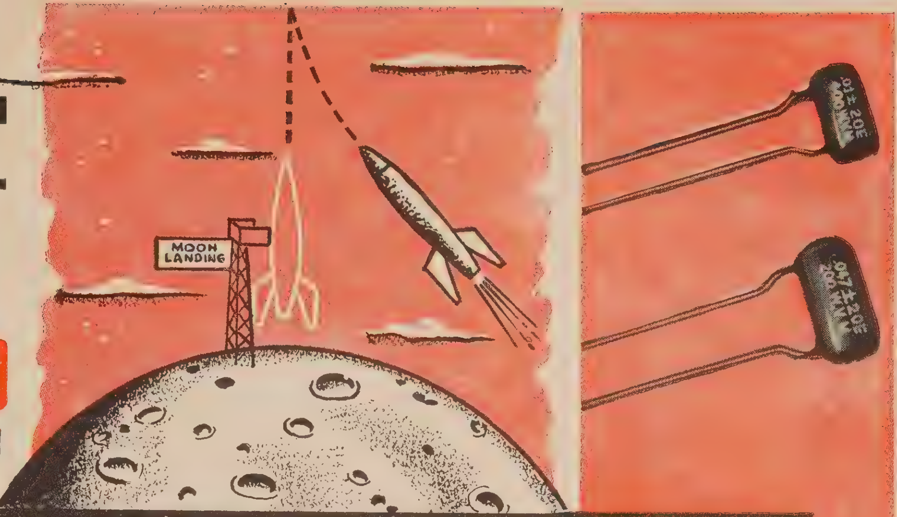

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"Reliability Anatomy for System Design Engineers," *E. S. Winlund, General Electric Co., Phoenix, Ariz.*

"A Complete Reliability Analysis of a One-Unit System," *R. E. Barlow and L. C. Hunter, Sylvania Electronic Defense Lab., Mountain View, Calif.*

"Statistical Pitfalls for the Reliability Engineer," *G. H. Beckhart, Radio Corp. of America, Moorestown, N. J.*

"The Use of IBM Cards to Predict, Control, and Measure Reliability of a Missile Electronics Unit," *G F. Dolan, Hughes Aircraft Co., Culver City, Calif.*

"System Improvement Through Failure Effect and a Reliability Model," *G. E. Unruh, Paramount Electronics, Inc., Hicksville, N. Y.*

Session 2.4—Antennas

Moderator: *Dr. W. J. Otting, Jr., Director of Physical Sciences, Air Force Office of Scientific Res., Washington, D. C.*

"Ferromagnetic Antennas," *R. New, American Electronic Labs., Inc., Lansdale, Pa.*

"Effect of Antenna Phase Pattern on Doppler System Operation," *H. S. Rothman and W. E. Scharfman, Stanford Research Inst., Menlo Park, Calif.*

"A Generalized Analysis of Electronic Antenna Beam Steering," *P. D. Kennedy, Lockheed Aircraft Corp., Sunnyvale, Calif.*

"The Effect of Field Wire Stability on the Maximum Length of Loop," *N. W. Feldman and G. P. Tripp, Hqs, U. S. Army Signal Research and Development Lab., Fort Monmouth, N. Y.*

"The Shroud Antenna for High Speed Missiles," *V. W. Richard, Ballistic Research Lab., Aberdeen Proving Ground, Md.*

"Ring Arrays," *W. D. Nelson, General Electric Co., East Dewitt, N. Y.*

Session 2.5—Ranging, Tracking and Reconnaissance

Moderator: *Dr. J. A. Boyd, Director, Willow Run Labs., University of Michigan, Ann Arbor, Mich.*

"A Continuous Wave Range System," *F. C. Lanza, Philco Corp., Palo Alto, Calif.*

"An Experimental Study of Monopulse Technique for Ground Clutter Discrimination," *S. Y. Chang and V. Stabilito, U. S. Army Ordnance, Frankford Arsenal, Philadelphia, Pa.*

"Tracking Research at the Naval Training Device Center," *G. Micheli, U. S. Naval Training Device Center, Port Washington, N. Y.*

"On the Tracking and Geodetic Potentialities of a Doppler Rate Measuring System," *D. C. Brown, RCA Service Co., Patrick Air Force Base, Fla.*

"Instrumentation Error Analysis of the AMR Missile Tracking System," *B. U. Glass, RCA Service Co., Patrick Air Force Base, Fla.*

"Statistical Method of Calculating Measurement Errors in Ranging and Tracking Checkout Systems" *L. G. Larson, Philco Corp., Palo Alto, Calif.*

Tuesday Afternoon

Session 3.1—Guidance and Space Technology (Confidential)

Sponsor: Air Research and Development Command.

Moderator: *To be announced.*

"Integrated Design of Antennas for Ballistic Missiles and Space Vehicles," *D. A. Alsberg, Bell Telephone Lab., Inc., Whippany, N. J. and H. W. Redlien, Wheeler Lab., Great Neck, L. I., N. Y.*

"The Space Surveillance System," *Dr. C. E. Cleeton, U. S. Naval Research Lab., Washington, D. C.*

"Orbit Determination for Passive Satellite Detection," *R. B. Patton, Jr., Ballistic Research Lab., Aberdeen Proving Ground, Md.*

"Evaluation of Reliability Prediction Techniques of the Electronics System of the Falcon Missile," *F. A. Barta, Hughes Aircraft Co., Culver City, Calif.*

"Reflections from Meteor Trails Meteorite Experiment," *D. Lynch and C. A. Bartholomew, U. S. Naval Research Lab., Washington, D. C.*

"A Proposed 24-Hour Communications Satellite System," *J. V. Michaels, G. N. Krassner and J. E. Bartow, U. S. Army Signal Res. and Dev. Lab., Fort Monmouth, N. J.*

Session 3.2—Data Handling II

Moderator: *To be announced.*

"Research and Development of New Computer Programming Techniques Required for Mechanization of Machine Learning," *Dr. R. E. Smith, Control Data Corp., Minneapolis, Minn.*

"Pattern Recognition," *J. W. Brouillette and C. W. Johnson, General Electric Co., Syracuse, N. Y.*

"New Techniques in Residual Arithmetic," *M. R. Levine and J. Marx, American Bosch Arma Corp., Hempstead, N. Y.*

"A Note on the Applicability of Error-Correcting Codes," *J. E. Palmer, Radio Corp., of America, Camden, N. J.*

"A Real Time Telemetry Data Transmission System," *H. E. Rennacker, Collins Radio Co., Burbank, Calif.*

"Computer Controlled Automatic Diagnostic and Checkout System for Field Use," *R. J. Brachman, Frankford Arsenal, Philadelphia, Pa.*

Session 3.3—Special Electrical Components

Moderator: *To be announced.*

"Some Aspects of Tunnel Diode Applications," *T. O. Krueger, U. S. Army Signal Res. and Dev. Lab., Fort Monmouth, N. J.*

"The 'Rayistor' an Electrical Transformer Using Optical Coupling," *J. C. Davis, Jr., Raytheon Co., Bedford, Mass.*

"Thin Film Components Based on Tantalum," *R. W. Berry and N. Schwartz, Bell Telephone Lab., Inc., Murray Hill, N. J.*

"Non Steady-State Thermoelectric Generators," *S. R. Hawkins, Lockheed Aircraft Corp., Sunnyvale, Calif.*

"New Developments in the Field of Military Quartz Crystals," *G. K. Guttwein, U. S. Army Signal Res. and Dev. Lab., Fort Monmouth, N. J.*

Session 3.4—Radar

Moderator: *To be announced.*

"Precision Recording of Radar Operation," *C. M. Redman, Hq, White Sands Missile Range, N. M.*

"System Evaluation of Low Noise Radar Sensitivity," *S. Charton and G. Ver Wys, Radio Corp. of America, Moorestown, N. J.*

"The Implementation of the Integrated Mapping System," *J. Boyajean, Fairchild Camera and Instrument Corp., Syosset, L. I. N. Y.*

"A Flush-Mounted VHF Telemetry Antenna with Hemispherical Coverage," *R. C. Payne and P. Painter, Jr., Dynatronics, Inc., Orlando, Fla.*

"The Limitations of Angular Radar Resolution," *Dr. E. Eichler, U. S. Army Ordnance, Frankford Arsenal, Philadelphia, Pa.*

"Internal Ballistic Measuring System," *L. Adelson, Picatinny Arsenal, Dover, N. J.*

Session 3.5—Simulation General

Moderator: *Dr. R. A. Weiss, Scientific Director, Army Research Office, Washington, D. C.*

"Space Simulation with High Gas Release Rates," *W. W. Balwanz and J. M. Singer, Naval Res. Lab., Washington, D. C.*

"Tank vs Tank Synthetic Gunnery Trainer," *I. Friedland, U. S. Naval Training Device Center, Port Washington, N. Y.*

"Radar Simulation," *C. Colbert, Westgate Lab., Inc., Yellow Springs, Ohio.*

"Mathematical Models of Multiple-Gimbal Systems," *Dr. A. Rosenfeld, Budd Lewyt Electronics, Inc., Long Island City, N. Y.*

"Optimization of Test Systems," *J. C. O'Brien, Cooper Development Corp., Monrovia, Calif.*

"Optimum Search Routines for Automatic Fault Location," *S. I. Firstman, The Rand Corp., Santa Monica, Calif., and B. Gluss, Armour Research Foundation of Illinois, Chicago.*

Wednesday Morning, June 29

Session 4.1—Electronic Generation, Switching and Radiation (Confidential)

Sponsor: Air Research and Development Command.

Moderator: *R. I. Cole, Manager, Military Projects Planning, Melpar, Inc., Falls Church, Va.*

"A Very High Gain Experimental Millimeter Foster Scanner," *C. A. Hacking, I-T-E Circuit Breaker Company, Philadelphia, Pa.*

"A Special Purpose Microwave Switch for Anti-jam Operation of Conical Scanning Radars," *S. D. Schreyer and G. Klein, Westinghouse Electric Corp., Baltimore, Md.*

"A Periodically-Focused 10 KW Microwave Traveling-Wave Amplifier," *O. T. Purl and K. W. Slocum, Watkins-Johnson Co., Palo Alto, Calif.*

"Electromagnetic Radiation in Sea Water," *E. J. Hilliard, U. S. Naval Underwater Ordnance Station, Newport, R. I.*

"Self-Focusing Technique for Large Arrays," *P. W. Howells, General Electric Co., Dewitt, N. Y.*

"A Radar Technique Using an Electro-Optical Two-Dimensional Filter, Part I—Principles of Operation, Part II—An Experimental Model Employing a Delay-Line Light Modulator," *L. Lambert, Moses Arm, and Isaac Weissman, Columbia Univ., New York, N. Y.*

Session 4.2—Communications II

Moderator: *To be announced.*

"Operational Testing of a Long Range Rocket Communication System," *B. J. Huffman, Hughes Aircraft Corp., Culver City, Calif., and W. F. O'Neil, C & N Lab. WADD, Wright-Patterson AFB, Ohio.*

"A Long Range Rocket Communication System," *W. L. Exner and E. R. Gaul, Hughes Aircraft Co., Los Angeles, Calif.*

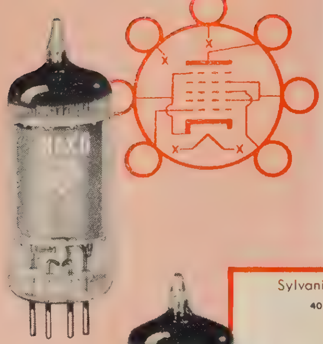
Electron Tube News ...from SYLVANIA

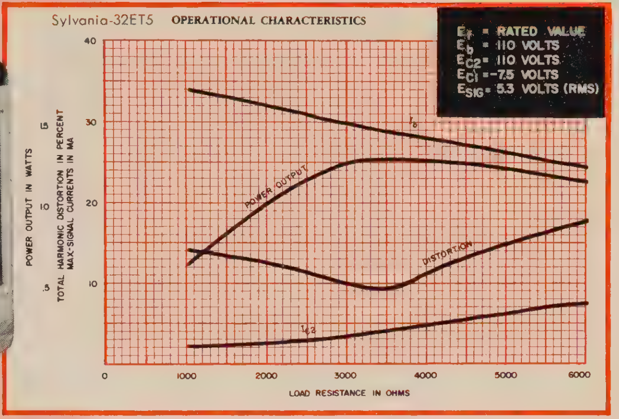
6AM3
12ET5
55 65 70 90 100 130 140 160
90 120 130 160

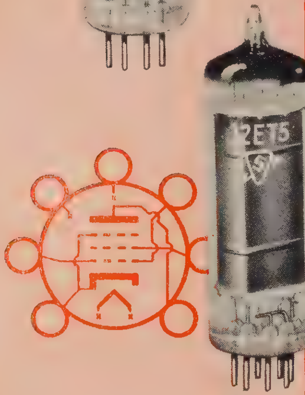
Cool operation sparks home-radio sales when you design around

SYLVANIA 100-mA ALL-AMERICAN FIVE

Originated by Sylvania—the 100-mA All-American Five requires ⅓ less heater power, opens new design possibilities and offers significant merchandising opportunities. Now, tube layout is comparatively unrestricted, cabinet styling is more flexible. Cost reductions in cabinetry, circuitry and components are within easy grasp. Tube reliability is enhanced. Printed circuit techniques can be used advantageously. Here, then, are important advances in home radio design—made possible by the Sylvania 100-mA All-American Five.

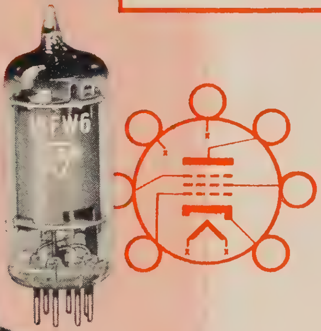




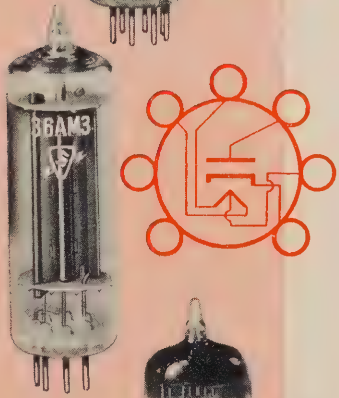


Named to the All-American Five are: 18FW6, semi remote cut-off pentode; 18FX6, pentagrid converter 18FY6 high mu triode-double diode; 32ET5, bean power pentode; and the 36AM3, half-wave rectifier—a tube complement with proven field experience.

Lower ambient temperature increase design flexibility and offer substantial economies. Radio cabinets utilizing this carefully mated complement show temperature reductions of 20-25%. The area of the power output tube shows an even greater temperature decrease—as much as 30%. As a result, less expensive plastics can be used. Vertical chassis can be designed without special heat shielding. Placement of the power output tube is no longer critical because of heat—wide, outside "berths" are unnecessary—designs can be compact. Printed circuit boards may be used without deterioration in set life and performance caused by high ambient temperatures.

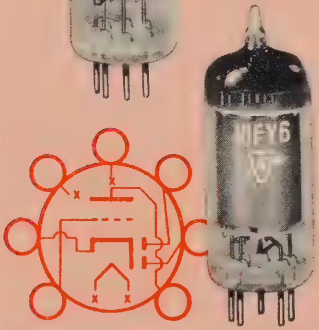


Tube reliability is increased. Sylvania heater design of the 100-mA line provides for more balanced distribution of the heater voltages in the heater string. Surge voltages across individual tubes are minimized.



Sylvania 100-mA All-American Five can be used in existing 150-mA designs with a minimum of redesign time. The 100-mA tube complement presents many advantages that can be directly translated into consumer benefits and increased home radio sales.

New developments in the 100-mA line. Sylvania is developing further tube complements that will incorporate the inherent advantages of a cooler-operating 100-mA line. These include a four tube line for home radio sets, a complement for FM radio receivers, and two new types that hold exciting possibilities for quantity-produced Hi-Fi.



Your local Sylvania Sales Engineer will gladly give you the whole story on the Sylvania 100-mA line. Call him or write Electronic Tubes Division, Sylvania Electric Products Inc., Dept. 195, 1740 Broadway, New York 19, New York.

SYLVANIA

Subsidiary of **GENERAL TELEPHONE & ELECTRONICS**

"Impact of the Recent International Radio Conference, Geneva, on USAF Communications-Electronics Programs," *C. W. Loeber, Dept. of Air Force, Washington, D. C.*

"Communication by Re-radiation from Chaff," *B. V. Blom, Benson, Ariz.*

"Use of Faraday Rotations in Prediction of Ionospheric Disturbances," *H. S. Marsh, Watkins Johnson Co., Palo Alto, Calif.*

"Digital Battlefield Communications," *W. C. Slagle, Stromberg-Carlson, San Diego, Calif.*

Session 4.3—Reliability II

Moderator: *W. S. Marks, Jr.*

"Participation in the Fleet Ballistic Missile Weapon System Component Reliability and in the Interservice Data Exchange Programs," *S. I. Pollock, U. S. Naval Ordnance Laboratory, Corona, Calif.*

"Application of an Environmental Probe Test Technique for Improving the Reliability of a Guided Missile Fuze," *B. W. Teres, Diamond Ordnance Fuze Lab., Dept. of the Army, Washington, D. C.*

"Reliability of a Parallel System Considering Load Redistribution," *C. H. Tsao and H. L. Leve, Hughes Aircraft Corp., Culver City, Calif.*

"Understanding and Improving System Reliability and Maintainability, Using Information in Engineering/Environmental Malfunction Data Samples," *G. H. Allen, Raytheon Co., Maynard, Mass.*

"The Reliability of Hermetically Sealed Equipment," *W. B. Rossnagel, Kearfott Div. of General Precision, Little Falls, N. J.*

Session 4.4—Systems Ancillary to Missiles

Moderator: *To be announced.*

"Equipment Design Trends in Missile Scoring Devices," *W. Ficklin, A. H. Maciszewski, J. J. Pakan and K. Ringer, A. R. F. Products, Inc., River Forest, Ill.*

"System Integration Factors in V/Stol Launched Air-to-Surface Missile," *I. H. Rubaii, International Business Machines Corp., Owego, N. Y.*

"Electric Firing of Fully Combustible Ammunition," *F. J. Dashnaw, Watervliet Arsenal, Watervliet, N. Y.*

"Airborne Instrumentation Systems Utilized in First and Second Generation Ballistic Re-entry Vehicles," *L. E. Foster, General Electric Co., Philadelphia, Pa.*

"Flight Measurements on the JUPITER R&D Missile," *C. T. N. Paludan, Huntsville, Ala.*

Session 4.5—Simulation-Electronic

Moderator: *To be announced.*

"Electromagnetic Environment Simulation for System Trainers," *F. P. Cullen, W. Helf, and J. K. Scully, The Marquardt Corp., Pomona, Calif.*

"The Development of a Dynamic Target and Countermeasures Simulator," *R. L. Norton, U. S. Army Signal Missile Support Agency, White Sands Missile Range, N. M.*

"All Electronic Visual Flight Simulator," *P. L. Fox, Aerojet-General Corp., Azusa, Calif.*

"Celestial Navigation Trainer," *G. Jaquiss, U. S. Naval Training Device Center, Port Washington, N. Y.*

"ASW Submarine Target, Device 21B12, Type 1, "*R. H. Dickman, U. S. Naval Training Device Center, Port Washington, N. Y.*

"Tank Turret Trainer, Device 3T1," *T. Mongello, U. S. Naval Training Device Center, Port Washington, N. Y.*

Wednesday Afternoon

Session 5.1—Instrumentation IV —(Confidential)

Sponsor: Air Research and Development Command.

Moderator: *D. J. McLaughlin, U. S. Naval Res. Lab., Washington, D. C.*

"Transmission of Electromagnetic Waves Through An Ionized Medium in the Presence of a Stron Magnetic Field," *T. P. Harley, Boeing Airplane Co., Seattle, Wash.*

"The Exploitation of Millimeter Waves for Military Applications," *H. N. Tate, Hq. U. S. Army Signal Res. and Dev. Lab., Fort Monmouth, N. J.*

"A Millimeter Wave Radar System," *J. M. DeBell, Jr., Allen B. DuMont Lab., Inc., Clifton, N. J.*

"Increased Jamming and Reconnaissance Effectivity Through Polarization Diversity," *E. F. Henry, Melpar, Inc., Falls Church, Va.*

"Countermeasures Techniques for Use Against Frequency-Jump Radars," *G. E. Austin, Sylvania Electronic Defense Lab., Mountain View, Calif.*

Session 5.2—Space Technology

Moderator: *Dr. H. K. Ziegler, Chief Scientist, U. S. Army Signal Res. and Dev. Lab., Fort Monmouth, N. J.*

"Maintenance, Repair and Assembly in Space by Remote Means," *J. W. Clark, Hughes Aircraft Co., Culver City, Calif.*

"The Able-4 Thor Deep Space Probe," *P. F. Glaser, Space Technology Labs., Inc., Los Angeles, Calif.*

"Communication in Space by Deflected Sunlight," *K. W. Otten, Wright Air Development Div., Wright-Patterson AFB, Ohio.*

"Optimum Capacitor Charging Efficiency for Space Systems," *Dr. P. M. Mostov, Dr. J. L. Neuringer and D. S. Rigney, Republic Aviation Corp., Farmingdale, N. Y.*

"Application of Inertial Techniques to Interplanetary Navigation," *M. J. Minneman, Republic Aviation Corp., Farmingdale, N. Y.*

Session 5.3—Camera Display Devices

Moderator: *To be announced.*

"High Performance Camera Tube Program," *S. Gray, RCA Labs., Princeton, N. J.*

"High Speed Direct Electronic Printing Cathode Ray Tube," *N. Fyler, D. Cone, R. Dorr, J. Wurtz, Litton Industries, San Carlos, Calif.*

"Extending the Dynamic Range of Camera Tubes Employing Return Beam Modulation," *A. D. Cope and H. Borkan, Radio Corp. of America, Princeton, N. J.*

"Image Orthicon Tubes as Image Intensifiers," *N. Swanson, U. S. Army Engineer Res. and Dev. Lab., Fort Belvoir, Va.*

"Three-Dimensional Direct-View Display Tube," *R. D. Ketchpel, Huges Aircraft Co., Culver City, Calif.*

Session 5.4—Vulnerability, Guidance and Control

Moderator: *W. S. Hinman, Jr. Technical, Director, Diamond Ordnance Fuze Lab., Ordnance Corps, U. S. Army, Washington, D. C.*

"Loran-C Navigation System," *W. Dickinson, Jansky and Bailey, Inc., Washington, D. C.*

"Abstract of MATTS System (Multiple Airborne Target Trajectory System)," *W. J. Zable, Cubic Corp., San Diego, Calif.*

"A New Gyro for Autopilot Use," *S. Dardarian, General Precisions, Inc., Little Falls, N. J.*

"Lightweight Inertial Systems," *R. E. Marcille, Litton Industries, Beverly Hills, Calif.*

"Inertial Accelerometers—Their Nature, Character and Limitations," *M. Manerer, General Precision, Inc., Little Falls, N. J.*

"Jamming Effectiveness Instrumentation," *Capt. C. H. Redwin and C. H. Meyer, III, Rome Air Dev. Center, Griffiss AFB, N. Y.*

Session 5.5—Data Handling

Moderator: *To be announced.*

"High Speed Auto-Data System for Blast Studies," *R. D. Jones and J. D. Smith, Sandia Corp., Sandia Base, Albuquerque, N. M.*

"Data Acquisition for a Research and Development Test Stand," *T. Wong and R. L. Thomason, U. S. Naval Ordnance Test Station, China Lake, Calif.*

"The Handling of UDOP Data," *D. H. Parks, Radio Corp. of America, Patrick AFB, Fla.*

"Description of Automatic Data Reduction Facility Combining Maximum Versatility and Speed," *W. R. Schumacher, U. S. Navy Underwater Sound Lab., New London, Conn., and H. M. Wilkinson, Epsco, Inc., Cambridge, Mass.*

"The Digitron—A High Speed Data Display System," *P. J. Meredith, D. J. Griffin, and F. A. Paulus, The Marquardt Corp., Pomona, Calif.*

Professional Groups*

Aeronautical & Navigational Electronics (G-11)—L. M. Sherer, RTCA, Bldg. T-5, 16 and Constitution Ave., N.W., Washington 25, D. C.; H. R. Mimno, Harvard Univ., Cambridge, Mass.

Antennas & Propagation (G-3)—A. Dorne, Dorne and Margolin, Westbury, L. I., N. Y.; S. A. Bowhill, Pennsylvania State Univ., University Park, Pa.

Audio (G-1)—H. S. Knowles, Knowles Electronics, 9400 Belmont Ave., Franklin Park, Ill.; Prof. A. B. Bereskin, E.E. Dept., Univ. of Cincinnati, Cincinnati 21, Ohio; M. Camras, Armour Res. Found. Tech. Ctr., Chicago 16, Ill.

Automatic Control (G-23)—J. E. Ward, Servomechanisms Lab., M.I.T., Cambridge 39, Mass.; G. S. Axelby, Westinghouse Air Arm Div., Friendship Airport, Baltimore 3, Md.

Broadcast & Television Receivers (G-8)—R. R. Thalner, Sylvania Home Electronics, 700 Ellicott St., Batavia, N. Y.; C. W. Sall, RCA, Bldg. 13-4, Camden, N. J.

Broadcasting (G-2)—G. E. Hagerty, Westinghouse Elec. Corp., 122 E. 42 St., Suite 2100, N. Y. 17, N. Y.; W. L. Hughes, E.E. Dept., Iowa State College, Ames, Iowa.

Circuit Theory (G-4)—S. Darlington, Bell Telephone Labs., Murray Hill, N. J.; W. Bennett, Bell Telephone Labs., Murray Hill, N. J.

Communications Systems (G-19)—J. E. Schlaikjer, IT&T Co., 67 Broad St., N. Y. 4, N. Y.; M. R. Donaldson, Electronic Comm. Inc., St. Petersburg, Fla.

Component Parts (G-21)—J. J. Drvostep, Sperry Gyroscope Co., Mail Station 1A 36, Great Neck, L. I., N. Y.; G. Shapiro, Engineering Electronics Sec., Div. 1.6, NBS, Connecticut Ave. and Van Ness St., Washington, D. C.

Education (G-25)—J. G. Truxal, Head, Dept. of E.E., Polytechnic Inst. of Brooklyn, Brooklyn, N. Y.; W. R. LePage, Dept. of E.E., Syracuse Univ., Syracuse, N. Y.

Electron Devices (G-15)—W. M. Webster, Semi-Conductor Div., RCA, Somerville, N. J.; E. L. Steele, Hughes Prods., Inc., International Airport Station, Los Angeles 45, Calif.

Electronic Computers (G-16)—A. A. Cohen, Remington Rand Univac, St. Paul 16, Minn.; R. O. Endres, Rese Engrg. Co., Philadelphia, Pa.; H. E. Tompkins, Moore School of E.E., Univ. of Pennsylvania, Philadelphia.

Engineering Management (G-14)—H. M. O'Bryan, Sylvania Elec. Prods., 730 3rd Ave., N. Y. 17, N. Y.; A. H. Rubenstein, Northwestern Univ., Evanston, Ill.

Engineering Writing and Speech (G-16)—T. T. Patterson, Jr., RCA, Bldg. 13-2, Camden, N. J.; H. B. Michaelson, IBM Res. Center, Box 218, Yorktown Heights, N. Y.

Human Factors in Electronics (G-28)—C. M. Jansky, Royal McBee Corp., Portchester, N. Y.; J. I. Elkind, Bolt, Beranek and Newman, Cambridge, Mass.

Industrial Electronics (G-13)—J. E. Eiselein, RCA Victor Div., Camden, N. J.; R. W. Bull, Armour Res. Found., Chicago, Ill.

Information Theory (G-12)—P. Elias, M.I.T., Rm. 26-347, Cambridge 39, Mass.; A. Kohlenberg, Melpar Inc., 43 Leon St., Boston 15, Mass.

Instrumentation (G-9)—C. W. Little, C-Stellerator Assoc., Box 451, Princeton, N. J.; G. B. Hoadley, Dept. of E.E., North Carolina State College, Raleigh, N. C.

Medical Electronics (G-18)—W. E. Tolles, Airborne Instruments Lab., 160 Old Country Rd., Mineola, L. I., N. Y.; L. B. Lusted, Univ. of Rochester Medical School, Strong Memorial Hosp., Rochester 20, N. Y.

Microwave Theory and Techniques (G-17)—A. A. Oliner, Microwave Res. Inst., 55 Johnson St., Brooklyn 1, N. Y.; D. D. King, Electronic Comm., Inc., 1830 York Rd., Timonium, Md.

Military Electronics (G-24)—H. Randall, 1208 Seaton Lane, Falls Church, Va.; D. R. Rhodes, Radiation Lab., Instrument Div., Orlando, Fla.

Nuclear Science (G-5)—A. B. Van Rennes, United Res. Inc., Tech. Div., 128 Alewife Brook Pkwy., Cambridge, Mass.; R. F. Shea, Dig Power Plant Engrg., Knolls Atomic Power Lab., General Electric Co., Schenectady, N. Y.

Production Techniques (G-22)—L. M. Ewing, General Electric Co., HMEED CSP-3, Syracuse 1, N. Y.; A. R. Gray, Rte. #1, Box 940, Orlando Vineland Rd., Wintergarden, Fla.

Radio Frequency Interference (G-27)—J. P. McNaul, U. S. Signal Corps., Hdqrs. Ft. Monmouth, N. J.; P. O. Schreiber, Technical Wire Prods., Springfield, N. J.

Reliability and Quality Control (G-7)—P. K. McElroy, General Radio Co., 22 Baker Ave., West Concord, Mass.; E. J. Breiding, IBM Corp., Kingston, N. Y.

Space Electronics and Telemetry (G-10)—C H. Hoeppner, Radiation, Inc., Melbourne, Fla.

Ultrasonics Engineering (G-20)—W. Roth, Roth Lab., 1240 Main St., Hartford 3, Conn.; O. Mattiat, Aerophysics Dev. Corp., P.O. Box 689, Santa Barbara, Calif.

Vehicular Communications (G-6)—A. A. MacDonald, Motorola, Inc., 4545 Augusta Blvd., Chicago 51, Ill.; R. P. Gifford, General Electric Co., Syracuse, N. Y.

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* Names listed are Group Chairmen and Transactions Editors.

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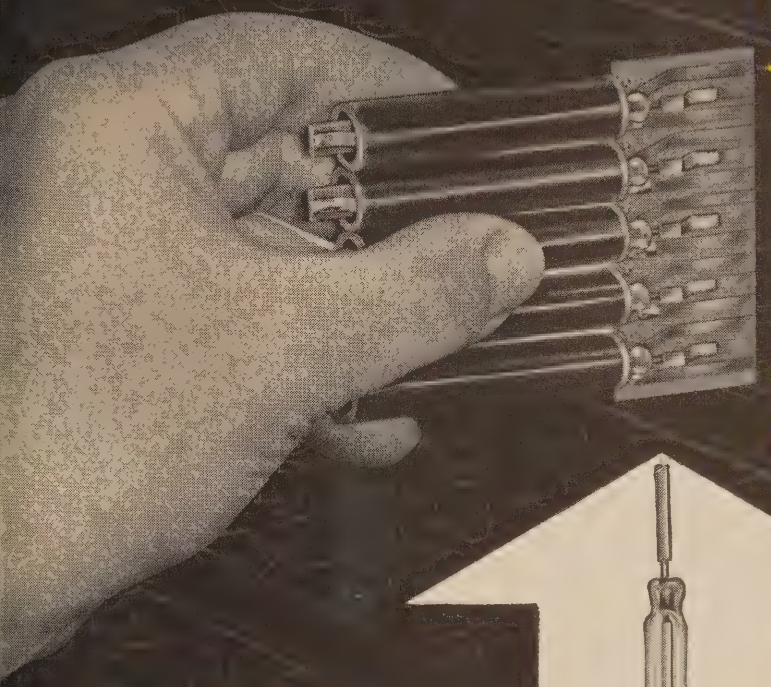

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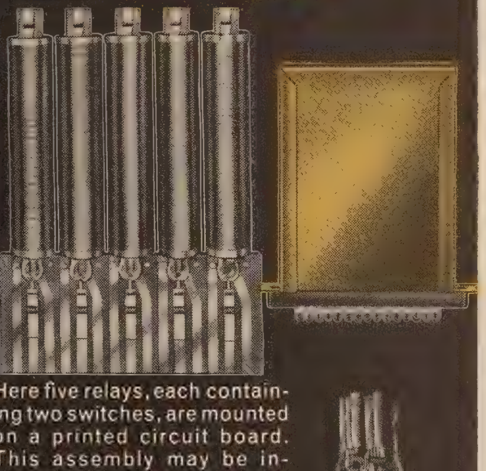

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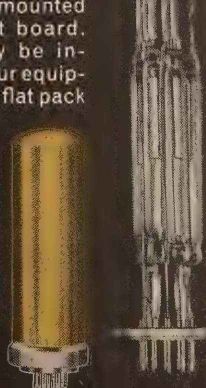
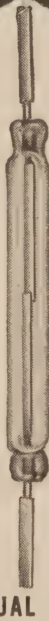


These six switches are clustered to form the core of a single electromagnetic coil, and encased in a cylindrical steel container.



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India—Officers to be elected.

Indianapolis (5)—G. R. Fraser, U. S. Naval Avionics Facility, 21 St. & Arlington Ave., Indianapolis 18, Ind.; C. E. David, 6110 E. 21 St., Indianapolis 18, Ind.

Israel—Israel Cederbaum, 117-13, Ramot Remez, Haifa, Israel; Ephraim Weissberg, 4 Shalom Aleihem St., Haifa, Nave Shaanan, Israel.

Italy—Algeri Marino, Via Guido d'Arezzo 14, Rome, Italy; Giuseppe P. Tarchini, Laboratorio Ricerche Elettr., Via Del Parlamento N. 33, Borgolombardo, Milan, Italy.

Ithaca (1)—C. E. Ingalls, 106 Sheldon Rd., Ithaca, N. Y.; N. H. Bryant, School of Elec. Engrg., Cornell University, Ithaca, N. Y.

Kansas City (6)—N. E. Vilander, 2509 W. 83rd St., Kansas City 15, Mo.; F. A. Spies, Bendix Aviation Corp., Box 1159, Kansas City 41, Mo.

Little Rock (6)—V. L. Dillaplain, 203 S. Pine St., Little Rock Ark.; R. V. Anders, 1814 Wolfe St., Little Rock, Ark.

London (8)—J. A. Fulford, Physics Dept., Univ. of Western Ontario, London, Ont., Canada; D. Moore, R.R. 3, Dorchester, Ont., Canada.

Long Island (2)—J. G. Stephenson, Airborne Instruments Lab., Walt Whitman Rd., Melville, N. Y.; J. Sinnott, 65 Jester Lane, Levittown, N. Y.

Los Angeles (7)—B. Dempster, Electronic Engrg. Co. of California, 1601 E. Chestnut Ave., Santa Ana, Calif.; J. Lewi, Packard-Bell, 12333 W. Olympic, Los Angeles 64, Calif.

Louisville (5)—W. J. Ryan, 4215 Northwestern Pkwy., Louisville 12, Ky.; H. T. Smith, 2511 Saratoga Dr., Louisville, Ky.

Lubbock (6)—J. J. Criswell, 511 50 St., Lubbock, Tex.; J. P. Craig, Route 7, Lubbock, Tex.

Miami (3)—J. W. Keller, Jr., Miami Shipbuilding Corp., 615 S. W. Second Ave., Miami 36, Fla.; F. R. Macklin, 325 Malaga Ave., Coral Gables, Fla.

Milwaukee (5)—F. J. Lofy, 2258 S. 56 St., West Allis 19, Wis.; J. D. Horgan, 1530 N. Longwood Ave., Elm Grove, Wis.

Montreal (8)—R. B. Lumsden, 1680 Lepine St., St. Laurent 9, P.Q., Canada; H. H. Schwartz, 5212 King Edward Ave., Montreal 29, P.Q., Canada.

Newfoundland (8)—M. D. MacGray, Canadian Marconi Co., 3 Prescott St., St. John's, Newf., Canada; F. A. Mulloy, 55 Calver Ave., St. John's, Newf., Canada.

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North Carolina (3)—W. G. McAvoy, 500 Magnolia St., Winston-Salem, N. C.; W. E. Langford, 3260 Notingham Rd., Winston-Salem, N. C.

Northern Alberta (8)—Roy Usher, St. Albert, Alta., Canada; W. L. Storms, 12907 134 Ave., Edmonton, Alta., Canada.

Northern New Jersey (2)—G. D. Hulst, 73 Mt. Prospect Ave., Verona, N. J.; J. G. Kreer, Jr., 114 Mountain Ave., Bloomfield, N. J.

Northwest Florida (3)—W. F. Kirlin, 312 May Circle, Bens Lake Area, Eglin AFB, Fla.; H. H. Hufnagle, 1 Katherine Ave., Fort Walton Beach, Fla.

Oklahoma City (6)—T. K. McDonald, 205 W. Coe Dr., Midwest City, Okla.; Elmo Black, 1701 N. W., 35 St., Oklahoma City 18, Okla.

Omaha-Lincoln (5)—R. H. Ralls, 5835 William St., Omaha 6, Neb.; R. A. Stratbucker; University of Nebraska, College of Medicine, 42 & Dewey Ave., Omaha, Neb.

Orlando (3)—A. E. Linden, 3001 Nancy Court, Orlando, Fla.; J. R. Matzinger, 1825 Whitehall Dr., Winter Park, Fla.

Ottawa (8)—F. V. Cairns, Radio Div., National Res. Council, Ottawa, Ont., Canada; M. Yurko, 1295 Wesmar Drive, Ottawa, Ont., Canada.

Philadelphia (3)—W. A. Howard, National Broadcasting Co., 1619 Walnut St., Philadelphia 3, Pa.; H. J. Woll, 123 Third Ave., Haddon Heights, N. J.

Phoenix (7)—E. S. Shepard, Sr., 5716 N. 19th St., Phoenix, Ariz.; H. R. Hyder, III, 2523 N. 57th St., Phoenix, Ariz.

Pittsburgh (4)—A. E. Anderson, Westinghouse Res. Labs., Physics Proj. Labs., Beulah Rd., Churchill Borough, Pittsburgh 30, Pa.; W. P. Caywood, Jr., Box 179, RD 2, Murrysville, Pa.

Portland (7)—J. C. Riley, 2039 S.E. Yamhill St., Portland 14, Ore.; L. C. Hedrick, 35 S.W. 88 Ave., Portland 25, Ore.

Princeton (2)—Sylvan Fich, College of Engineering, Rutgers Univ., New Brunswick, N. J.; R. D. Lohman, RCA, Somerville, N. J.

Quebec (8)—Paul Du Berger, 1267 Villars Ave., Sillery, P.Q., Canada; Theodore Wildi, 1365 De Löngueiul, Quebec City, P.Q., Canada.

Regina (8)—L. E. McBride, 3211 Regina Ave., Regina, Sask., Canada; J. M. McNeil, 3147 Retallack St., Regina, Sask., Canada.

Rio de Janeiro—H. Bonapace, Rua Nascimento Silva 572, Ipanema, Rio de Janeiro, Brazil; Z. Fuzesi, Caixa Postal 2668, Rio de Janeiro, Brazil.

Rochester (1)—F. A. Mitchell, Stromberg-Carlson Co., 1400 N. Goodman St., Rochester 9, N. Y.; J. L. Wheeler, 535 Rondo Lane, Webster, N. Y.

Rome-Utica (1)—W. J. Kuehl, 5 Hoffman Road, New Hartford, N. Y.; R. A. Zachary, Jr., 11 Arbor Drive, New Hartford, N. Y.

Sacramento (7)—Xelis W. Godfrey, 3220 Fulton Ave., Sacramento 21, Calif.; A. O. Rohde, 3160 Adams Road, Sacramento 25, Calif.

St. Louis (6)—R. L. Frazier, 9707 Willow Creek Lane, Rock Hill 19, Mo.; R. D. Hill, Jr., 363 Gray Ave., Webster Groves 19, Mo.

Salt Lake City (7)—R. W. Haegele, c/o Eitel-McCullough Inc., 1678 S. Pioneer Rd., Salt Lake City, Utah; A. W. Vodak, Sperry Utah Engrg. Labs., 322 N. 21 W. Street, Salt Lake City, Utah.

San Antonio-Austin (6)—A. F. Hasbrook, Rt. 11, Box 207, San Antonio, Tex.; F. X. Bostick, Jr., 5002 Beverly Hills Dr., Austin 3, Tex.

San Diego (7)—R. E. Honer, 5462 Mary

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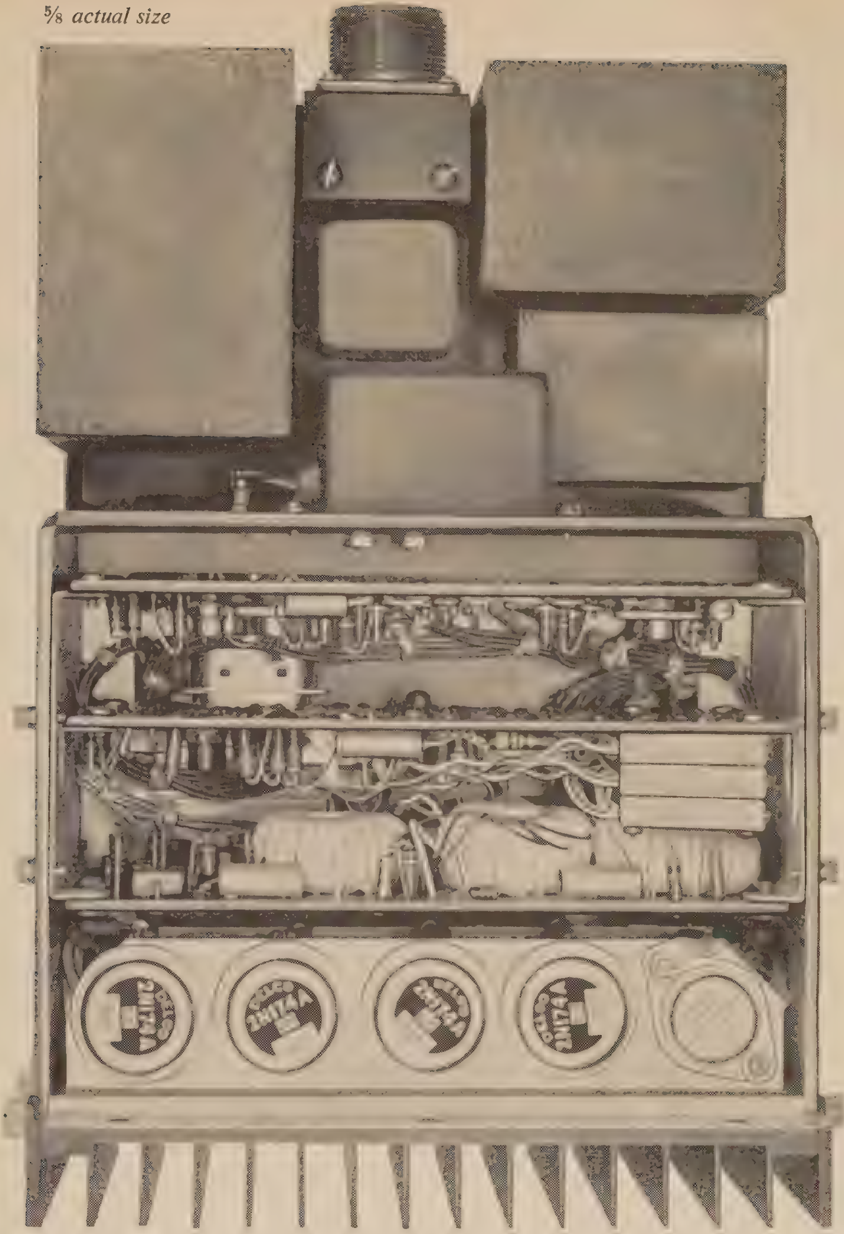

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Seattle (7)—L. C. Perkins, Box 307, Des Moines, Wash.; H. H. Judson, Jr., 2006 14 Ave., N., Seattle 2, Wash.

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South Bend-Mishawaka (5)—P. G. Cox, R.R.2, 10251 Harrison Rd., Osceola, Ind.; El L. Crosby, Jr., 400 S. Beiger St., Mishawaka, Ind.

South Carolina (3)—W. R. Boehm, Charleston Naval Shipyard, U. S. Naval Base, Code 210, Charleston, S. C.; H.L. Hunter, 49 Fort Dr., Rte. 6, N. Charleston, S. C.

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Tulsa (6)—Robert Broding, 2820 E. 39th, Tulsa, Okla.; P. M. Ferguson, 1133 N. Lewis, Tulsa, 10, Okla.

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Wichita (6)—J. W. D. Brown, 808 Governeour Road, Wichita, Kans.; R. F. Knowlton, 1200 North Derby, Derby, Kans.

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Winnipeg (8)—R. A. Johnson, Dept. of Electrical Engrg., The Univ. of Manitoba, Winnipeg, Man., Canada; H. T. Body, Siemens Bros. "Canada" Ltd., 419 Notre Dame Ave., Winnipeg 2, Man., Canada.

Subsections

Buenaventura (7)—J. E. Bossoletti, 2004 South "K" St., Oxnard, Calif.; R. L. O'Bryan, 757 Devonshire Dr., Oxnard, Calif.

Burlington (5)—P. D. Keser, Box 123, Burlington, Iowa; Cleo D. Cherryholmes, 2072 Highland, Burlington, Iowa.

East Bay (7)—D. O. Pederson, Elec. Engrg. Dept., University of Calif., Berkeley 4, Calif.; Eugene A. Aas, 2684 Kennedy St., Livermore, Calif.

Eastern North Carolina (3)—W. J. Barclay, Dept. of Elec. Engrg., North Carolina State College, Raleigh, N. C.; W. J. Speed, 2718 E. Rothgeb Dr., Raleigh, N. C.

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Kitchener-Waterloo (8)—George J. Dufault, 44 Ellis Crescent, North, Waterloo, Ont., Canada; C. L. Barsony, 169 Chapel St., Apt. 4, Kitchener, Ont., Canada.

Lancaster (3)—F. S. Veith, 366 Arbor Rd., Lancaster, Pa.; J. Evans, 2109 Lyndell Dr., Lancaster, Pa.

Las Cruces-White Sands Proving Ground (6)—H. Coleman, Box 1238, Las Cruces, N. Mex.; Secretary to be advised.

Lehigh Valley (3)—Leslie G. McCracken, Jr., 1782 W. Union Blvd., Bethlehem, Pa.; Joseph H. Volk, 411 Grant St., Easton, Pa.

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Merrimack Valley (1)—P. N. Hambleton, 382 Main St., Amesbury, Mass.; D. D. Sagaser, Bell Telephone Labs., 1600 Osgood St., North Andover, Mass.

Mid-Hudson (2)—R. R. Blessing, IBM Corp., Box 390, Dept. 569, Poughkeepsie, N. Y.; R. J. Domenico, IBM Research Lab., Poughkeepsie, N. Y.

Monmouth (2)—C. A. Borgeson, 82 Garden Road, Little Silver, N. J.; Paul E. Griffith, 557 Cedar Ave., West Long Branch, N. J.

Nashville (3)—Paul E. Dicker, Dept. of Elec. Engrg., Vanderbilt University, Nashville, 5 Tenn.; R. L. Hucaby, 945 Caldwell Lane, Nashville, 4, Tenn.

New Hampshire (1)—W. J. Uhrich, 107 Tolles St., Nashua, N. H.; F. L. Striffler, Ponemah Hill Rd., R.F.D. 2, Milford, N.H.

Northern Vermont (1)—L. M. Bundy, R.F.D. 1, Shelburne, Vt.; D. M. Wheatley, 14 Patrick St., South Burlington, Vt.

Orange Belt (7)—G. D. Morehouse, 3703 San Simeon Way, Riverside, Calif.; W. G. Collins, 958 Dudley, Pomona, Calif.

Panama City (3)—C. E. Miller, Jr., 603 Bunkers Cove Rd., Panama City, Fla.; Robert C. Lowry, 2342 Pretty Bayou Dr., Panama City, Fla.

Pasadena (7)—H. L. Richter, Jr., 4800 Oak Grove Dr., Pasadena, Calif.; Bertin N. Posthill, 56 Suffolk Ave., Sierra Madre, Calif.

Reading (3)—F. L. Rose, 42 Arlington St., Reading, Pa.; Harold S. Hauck, 216 Jameson Pl., Reading, Pa.

Richland (7)—C. A. Ratcliffe, 1601 N. Harrison St., Kennewick, Wash.; P. Richard Kelly, 220 Delafield, Richland, Wash.

San Fernando (7)—R. A. Lamm, 15573 Briarwood Dr., Sherman Oaks, Calif.; Jack D. Wills, 6606 Lindley Ave., Reseda, Calif.

Santa Ana (7)—T. W. Jarmie, 12345 Cinnabar Rd., Santa Ana, Calif.; R. F. Geiger, Aeronutronic, A Div. of Ford Motor Co., Ford Rd., Newport Beach, Calif.

Santa Barbara (7)—C. P. Hedges, 316 Coleman Ave., Santa Barbara, Calif.; J. A. Moseley, 4532 Via Huerto, Santa Barbara, Calif.

South Western Ontario (8)—W. A. Ruse, Bell Telephone Co., 1149 Goyeau St., Windsor, Ont., Canada; G. L. Virtue, 959 Rankin Blvd. Windsor, Ont., Canada.

Westchester County (2)—M. J. Lichtenstein, 52 Sprain Valley Rd., Scarsdale, N. Y.; Martin Ziserman, 121 Westmoreland Ave., White Plains, N. Y.

Western North Carolina (3)—L. L. Caudle, Jr., Box 2536, 1925 N. Tryon St., Charlotte, N. C., John I. Barron, Southern Bell T. & T. Co., Box 240, Charlotte, N. C.

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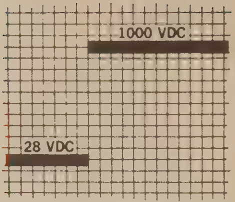

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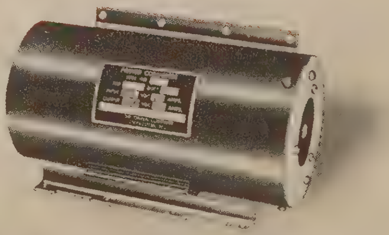

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NEWS New Products

New Cathode Ray Tubes

Three years of research & development in the laboratories of **Thomas Electronics Inc.**, Passaic, N. J., have resulted in a new technique in the manufacture of industrial-military cathode ray tubes used in instrument and radar applications. The development, involving new processes, techniques and materials, permits the aluminizing of cathode ray tubes operating with anode potentials of as low as 2 kilovolts. Previously tubes were aluminized only at high voltages greater than 5 to 6 kilovolts.

Aluminized cathode ray tubes offer many advantages, one of which is a substantial increase in the screen brightness. Brightness can now be augmented by as much as 90% in low voltage cathode ray tubes, resulting in an increase in the writing rate, which is especially desirable in photographic and visual applications. Alternatively, the increase in brightnesss permits a reduction in the beam current for the average display which results in a consequent reduction in line width and better overall resolution.

When the faceplate of an ordinary cathode ray tube is touched with the hand, the effect may be an impairment of the resolution of the display, or the display may shift its position. These adverse effects are eliminated with an aluminized screen, since its overall screen potential is made uniform by the conductivity of the aluminum layer.

Another advantage is the elimination of cathode glow and the back reflection of light from the walls of an aluminized cathode ray tube resulting in a marked improvement in contrast for photographic and visual applications. Other improvements include the reduction or elimination of ion burns for magnetic deflection types and significantly longer overall tube life and reliability.

The aluminizing development can be incorporated into the manufacture of all existing JEDEC cathode ray tubes operating in the range between 2 to 8 kilovolts. Prototypes of the 5ADP- and 5AQP-types will be made available shortly.

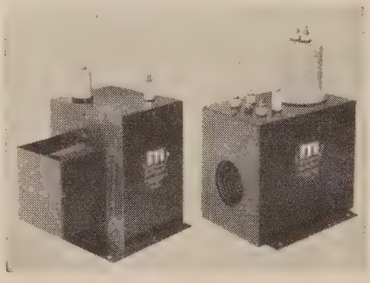
The first user of one of the low-voltage aluminized tubes is Analab Instrument Corp. which has worked jointly with Thomas in setting the specifications and has been evaluating performance of prototypes for oscilloscope applications.

In addition to oscilloscope applications, the tubes are suited for radar displays and any other display systems requiring the ultimate in light output and screen stability.

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

Pulse Transformers And Reactors

Custom engineered pulse transformers and their associated charging reactors are now available from **Manson Laboratories,** P. O. Box 1214, Stamford, Conn. Pulsed viewing transformers, mono-and bifilar types, and transformers for magnetron and klystron applications can be produced in quantity for circuits rated up to 250 kv. Illustrated in photo are two examples of this custom engineering: On the left a bifilar pulse transformer with recessed bellows providing a wide temperature tolerance, 30 kv rated output, step up ratio 1:5, the Bifilar Secondary supplies a magnetron with 3 amperes heater current. On the right; a charging reactor (4.5 henry), high "Q," linear over a wide dc current range, insulated for operation at 10 kv dc supply voltage. All components will meet applicable MIL specs when required.



Inquiries regarding special applications and specifications are invited. Brochure #XFR260 and data application forms are available upon request.

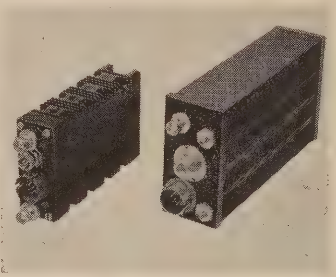
CGS Laboratories Now Trak Electronics

Elton T. Barrett, president, **CGS Laboratories, Inc.,** Wilton, Conn., announces that henceforth the company will carry on operations under the name of **Trak Electronics Co.** The corporate name remains unchanged for the present, and the business will be conducted under the name Trak Electronics Co., Division of CGS Laboratories, Inc.

In announcing the change, Mr. Barrett said: "The principal reasons for the change are the adoption of a name by another company similar to our corporate name, a desire to avoid the limitations implied by the word 'Laboratories,' and to facilitate promotion to the trade mark 'TRAK,' which already has acceptance in the trade."

Radar Beacon

Telerad Manufacturing Corp., 1440 Broadway, New York 18, N. Y., announces a new, compact radar beacon MODEL SRT-3081. The outstanding features of this beacon are:



Environmental conditions—Temperature: −54°C to +125°C. Vibration: 10 to 100 cps at 25 G. Acceleration: 50 G. Altitude: 60,000 ft. Shock: 15 G.

Receiver—Frequency range: 2750–2950 mc. Bandwidth: 6–12 mc at 3 db points 35 mc maximum at 40 db down.

Triggering sensitivity: −41 db (min.). Interrogation: Single or double pulse. Frequency stability: ±2 mc. Size $1\frac{1}{4}'' \times 2\frac{7}{8}'' \times 5\frac{3}{4}''$.

Transmitter—Frequency range: 2750–2950 mc. Frequency stability: ±2 mc. Pulse power: 100 watts peak (min.) Pulse repetition rate: 2000 pp. Pulse width: 0.65±0.05 microsecond. Delay: 1.5 microseconds. Range jitter: 0.1 microsecond. Size: $2'' \times 3\frac{5}{8}'' \times 7\frac{9}{16}''$. Weight: 3.45 lbs. Power supplies available on special order.

For more detailed information on this beacon and other Telerad products that embrace the L, S, C, X and K bands, write to the firm.

Connector Catalog

Automatic Metal Products Corp., 323 Berry St., Brooklyn 11, N. Y., has published a radio frequency connector guide and technical manual.

Over two years of extensive research, development and preparation has gone into the production of this coaxial connector volume.

In addition to the connector illustrations, diagrams, and numerical designations, this volume will contain technical information on the use of connectors, a comprehensive section devoted to coaxial cables, and complete cable assembly instructions for all connectors listed. An additional section devoted to Automatic's coaxial relays and switches is also included.

Further information may be obtained by writing to the firm.

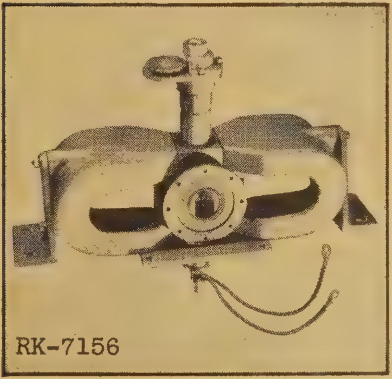
(Continued on page 192A)

Creative Microwave Technology

Published by MICROWAVE AND POWER TUBE DIVISION, RAYTHEON COMPANY, WALTHAM 54, MASS., Vol. 1, No. 9

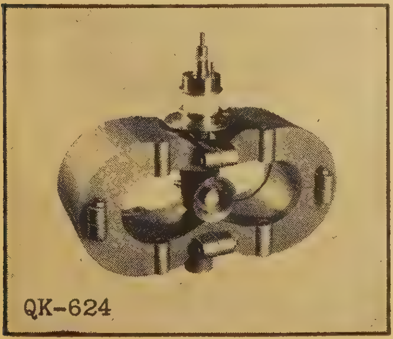
NEW RAYTHEON MAGNETRONS FOR A WIDE RANGE OF APPLICATIONS

Designed for C-band systems requiring tunability, the RK-7156 magnetron has a minimum peak power output rating of 250 kilowatts over a frequency range of 5,450 to 5,825 megacycles. Applications include a flight-tested, revolutionary airborne weather radar system. The RK-7156 is in quantity production.


RK-7156

* * *

X-band magnetron for airborne search radar provides one megawatt minimum peak power and 875 watts average power within a frequency range of 9,340 to 9,440 Mc. Designated QK-624, this pulsed-type tube is liquid cooled and should give at least 1,000 hours of reliable service.


QK-624

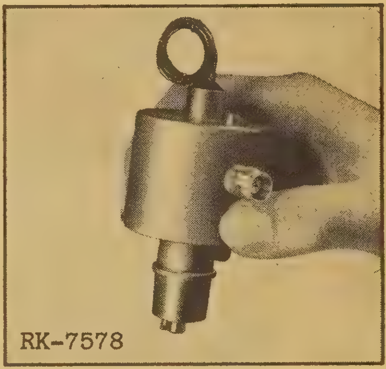
* * *

For ground-based and airborne radar systems, the RK-7529 magnetron provides a 2.0 microsecond pulse of 3.5 megawatts minimum peak power over 2,700 to 2,850 Mc. This liquid-cooled tube is interchangeable with other fixed-frequency S-band tubes operating at similar power levels.

RK-7529

* * *

A one kilowatt beacon magnetron, the RK-7578 weighs only 14 ozs., yet will withstand vibrations of 15 G's at 20 to 2,000 cycles and shock up to 100 G's. It is mechanically tunable and covers the 5,400 to 5,900 Mc range.


RK-7578

* * *

Developed to withstand extreme environmental conditions, the RK-7449 magnetron is a lightweight, compact tube with a minimum peak power output of 45 kilowatts at the operating frequency of 24 kmc. The RK-7449 is required to withstand repeated shocks of 50G. Stable operation is guaranteed at vibration frequencies up to 2,000 c.p.s. with 30G applied.

RK-7449

For the highest standard of Accuracy and Reliability

MARCONI INSTRUMENTS

for Precise Measurement

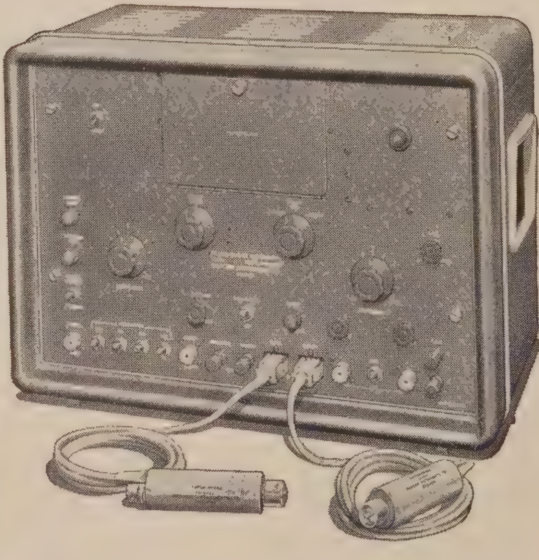
LOW CAPACITANCE BRIDGE
Model 1342

- Capacitance range: 0.002 $\mu\mu$F to 1,111 $\mu\mu$F, ± 0.2% accuracy.
- Shunt-resistance range: 1 to 1,000 MΩ.
- Suitable for in-situ measurements.
- Decade switching and readout.
- Independent indication of resistive component.

Capacitances down to 0.002 $\mu\mu$F can be measured with speed and precision by means of this three-terminal transformer ratio-arm bridge. Its exceptional discrimination and stability make it suitable for such applications as the measurement of the temperature coefficient of capacitors or changes in tube interelectrode capacitance. The bridge measures the capacitance between any two terminals of a 3-terminal network and is virtually unaffected by the impedance between either of these terminals and the third point. Connection to the component under test can be made via long leads without affecting measurement accuracy. Remote or wired-in components can be measured in-situ without the need to disconnect associated circuits.

20-MC SWEEP GENERATOR
Model 1099

Can be used in conjunction with any oscilloscope for direct display of video response characteristics up to 20 MC. Frequency is indicated by crystal-controlled marker pips, and a special circuit provides for differential amplitude measurements, enabling relative response to be determined with a discrimination better than 0.01dB. **Frequency Swept Output:** Frequency Range: Lower limit 100 kc, Upper limit 20 MC. Output level: Continuously variable from 0.3 to 3 volts. Output Impedance: 75Ω. **Time Base:** Repetition Rate: 50 to 60 cps. Output for c.r.o. X deflection: 250 volts. **Frequency Markers:** At 1 MC intervals; every fifth pip distinctive and crystal controlled.



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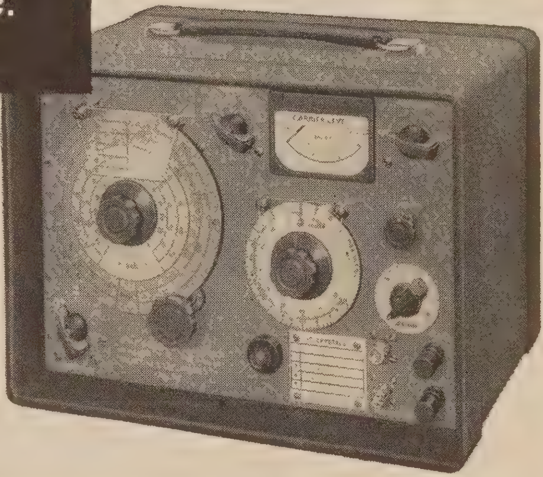
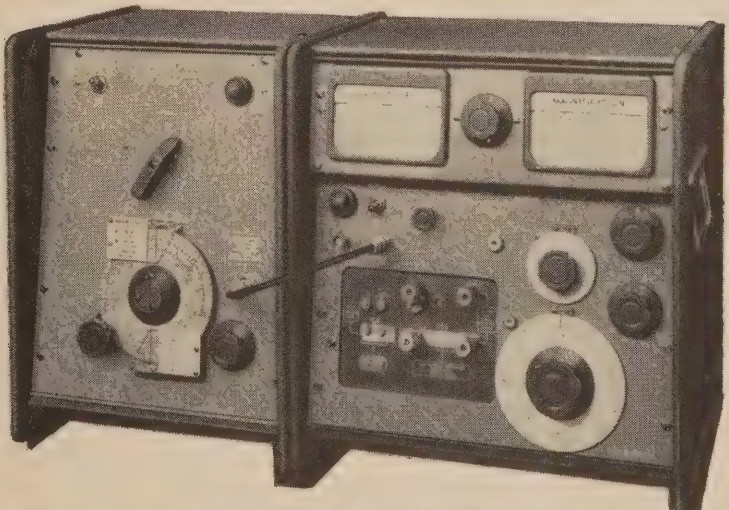
SPECTRUM & RESPONSE ANALYZERS
Q METERS & BRIDGES



Model 1064A/2 for MOBILE RADIO

This FM Signal Generator provides RF outputs of 30 to 50, 118 to 185, and 450 to 470 MC, with FM at one fixed deviation and 0-15 kc variable: IF crystal outputs at five spot frequencies, (xtals not supplied) and also an AF output. High frequency stability, quick warm up and accurate FM have been obtained by use of modern semi-conductor components. FM is produced by a varactor and the power supply is transistor stabilized with zener diode reference.



Q METER
Model 1245

Here for the first time is a single Q Meter covering the range AF to VHF.

Frequency Range: 1 kc to 300 MC. Measures Q: 5 to 1,000: accuracy 5% at 100 MC. **Q Multiplier:** x0.9 to x2. **Delta Q:** 25-0-25. Test Circuits: separate LF and HF test circuits have ranges of 1 kc to 50 MC and 20 to 300 MC. **Capacitance Range:** 7.5 to 110 μμF with 1-0-1 μμF incremental, for either test circuit; 20 to 500 μμF for LF test circuit. **Shunt Loss:** 12 MΩ at 1 MC, 0.3 MΩ at 100 MC. **External Oscillators:** Model 1247, 20 to 300 MC. Model 1246, 40 kc to 50 MC. Model 1101, 20 cps to 200 kc.

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TC170

VANE
AXIAL
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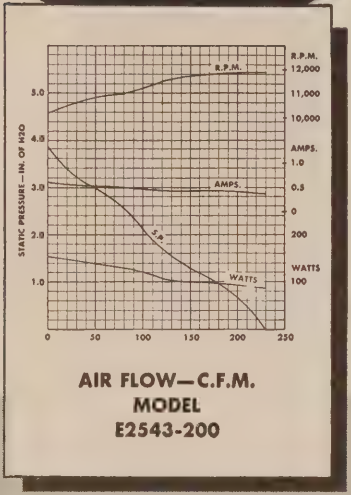
E-2543-200



SPECIFICATIONS:
200V 400 cps 3 phase
200 CFM at 3/4" S.P.
Weight: 3 lb. 8 oz.
Ambient: 85°C
Life: 5000 hrs.
Environmental MIL-E-5422D
Material MIL-E-5400B
Class F Insulation

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IRE People

Wayne D. Brodd (A'54), has been promoted to the position of advisory engineer in the IBM 7070 Engineering Department of the IBM Product Development Laboratory at Poughkeepsie, N. Y., where he is engaged in the New Product Engineering effort on the 7070 Unit Record Equipment, and system coordination with Endicott and Rochester Engineering groups.

He joined IBM in 1950 as a customer engineer trainee at Evanston, Ill. He was transferred to Poughkeepsie in 1953 as a technical engineer on the 702 input/output development and advanced to associate engineer in 1955 where he became engaged in work on the 774 Tape Data Selector. He attained the status of staff engineer in 1958, his position until his recent advancement.

Mr. Brodd is a graduate of the University of Illinois, Urbana, in 1950 with the B.S.E.E. degree.

❖

Donald W. Burns (A'56), has been advanced to the position of technical assistant to Arthur J. Hatch, vice president and general manager of Stromberg-Carlson's Commercial Products Division, according to an announcement issued by Mr. Hatch. Stromberg-Carlson is a division of General Dynamics Corporation.

D. A. Burns

In this new position Mr. Burns will be responsible for development and coordination of a variety of technical programs. Prior to this appointment he was chief engineer in the Commercial Products Division.

He has been with Stromberg-Carlson since 1954, when he joined the firm as a staff engineer to the manager of quality control in the Radio and Television Division. Subsequently he served as an engineer in the Research Division, as a senior design engineer in the Special Products Division, and as chief engineer of the Commercial Products Group in the Special Products Division. Earlier he had been a design development engineer with Sylvania Electric Products Corporation in Buffalo.

Mr. Burns attended the University of Buffalo and received the B.A. degree in mathematics from the University of Rochester. He is a member of the Rochester Society for Quality Control, and is chairman of the Committtee on Sound Apparatus of the Electronic Industries Association.

❖

Roy J. Sandstrom, Bendix Systems Division, General Manager, has announced the appointment of **James A. Burns** (A'54) as Director of Long Range Planning for the Bendix Systems Division. He will fill the position vacated by L. B. Young who recently became Assistant General Manager of the Division. Mr. Burns was formerly Head of Technical Planning under Mr. Young.

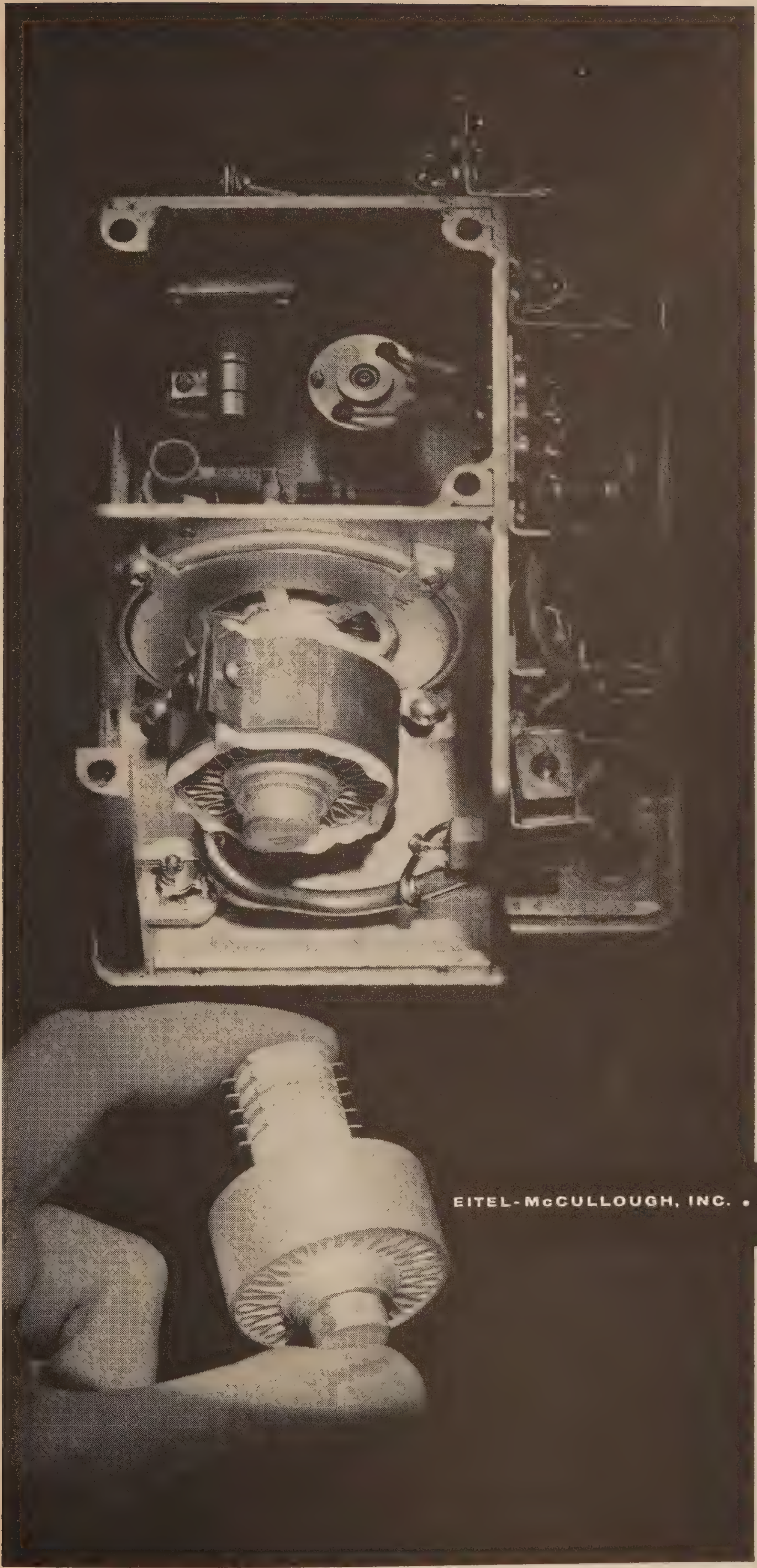
As the new Director of Long Range Planning, he will direct the Technical Planning and Marketing activities of the division and will coordinate customer requirements into the preliminary design studies as well as preparation and presentation of proposals. He will also integrate the capabilities of other Bendix Divisions and potential subcontractors into major systems investigation.

He received the B.S. degree in electrical engineering from the University of Michigan, Ann Arbor, in 1952, majoring in electronics. After graduation, he joined the Willow Run Laboratories of the University of Michigan Engineering Research Institute where he participated in the fields of analog computation, weapons systems design and analysis, air defense system design, communication equipment design and test, and battle area surveillance system and equipment design and analysis. During this period, he was Project Engineer on systems design for low-altitude defense and other weapons systems work.

In the field of battle area surveillance, he served from 1953 to 1957 in various capacities on Project Michigan, a triservice program to improve the intelligence gathering capabilities of the service. He was engaged primarily in radar system design and analysis, particularly in the field of MTI and the processing and display of radar data. He performed a survey of all existing or development radar equipment to establish its application to battle area surveillance. In addition, he performed detailed evaluation and test of several specific radar systems, particularly those employing MTI.

In addition to his work in radar, he also participated in the establishment of requirements for battle area surveillance systems, including evaluation and test, using television, microwaves, infrared, acoustics, and optical devices as well as navigational subsystems of both the ground-based and self-contained types. In this connection, he performed system design involving sensory devices, data processing and display techniques, and communications. He also participated in the test of battle area surveillance and intelligence processing equipment in large-scale Army maneuvers. He was a consultant to the Bendix Systems Division on air defense and air traffic control problems in 1956, and joined Bendix in January, 1957.

(Continued on page 50A)



SPACE AGE TV— WITH EIMAC CERAMIC TUBES

Lockheed's new miniature TV transmitter and camera have special significance for a space-curious world. They may one day help unravel some of the mysteries of the unknown as they soar through the outer reaches of space in a sophisticated sattelite.

At the heart of the tiny transmitter is an Eimac ceramic tetrode, the 4CX300A. Eimac ceramic tubes can take tough assignments like this in their stride, with performance "extras" that mean outstanding reliability.

Eimac advanced ceramic design makes possible a compact tube capable of maintaniing exceptional stability. Even under conditions of severe shock, vibration and accelerations up to 20g at frequencies from 20 to 2000 cycles per second no tube damage will result. Rugged, reliable power in a small package.

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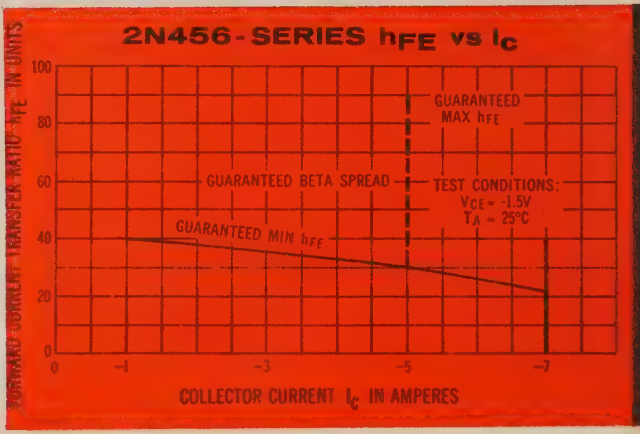
Today, over 40 ceramic tube types pioneered by Eimac engineering and research are available for use under adverse conditions. Whenever you have an application that requires compact tubes that *can take it*, investigate the many advantages of Eimac advanced ceramic-metal construction.

FULL LINE OF HIGHEST BETA GE

New TI high-efficiency emitter gives you high beta germanium power transistors!

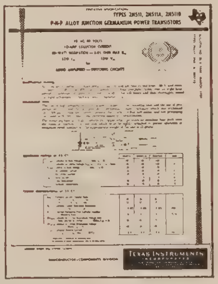
Now minimum and maximum betas are guaranteed from 20 to 60 at the maximum current rating f I_C = 25 amps in new TI 2N514 series tran-istors. New high efficiency emitter makes pos-ible greatly improved specifications for TI N456, 2N511, 2N512, 2N513, 2N514, and N1021 series alloy-junction germanium power ransistors.



I gives you design leadership in quality germanium power transistors

INCREASED BETA THROUGH HIGH-EFFICIENCY EMITTER

Emitter efficiency can be improved by increasing he ratio of resistivities between the emitter and ase region. For example, when a 10 ohm-entimeter resistivity germanium wafer is used s the base material, it is advantageous to have ess than a .01 ohm-centimeter resistivity emitter egrowth region. Since initial doping of the ermanium crystal establishes base resistivity, he ratio can be changed only by varying the mitter material. TI utilizes an emitter material hat results in a lower emitter resistivity and an ncreased emitter efficiency, plus providing the igher beta at high currents.


TYPES 2N511, 2N511A, 2N511B
P-N-P ALLOY JUNCTION GERMANIUM POWER TRANSISTORS
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Optimum reliability for all TI germanium power transistors is assured by . . . 100% testing . . . 100% temperature cycling . . . 100% hermetic seal testing . . . continuous and intensive quality assurance program. Write on your company letterhead for germanium power transistor specifications.

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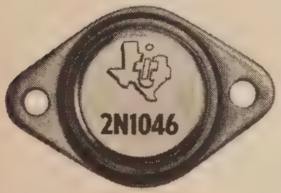
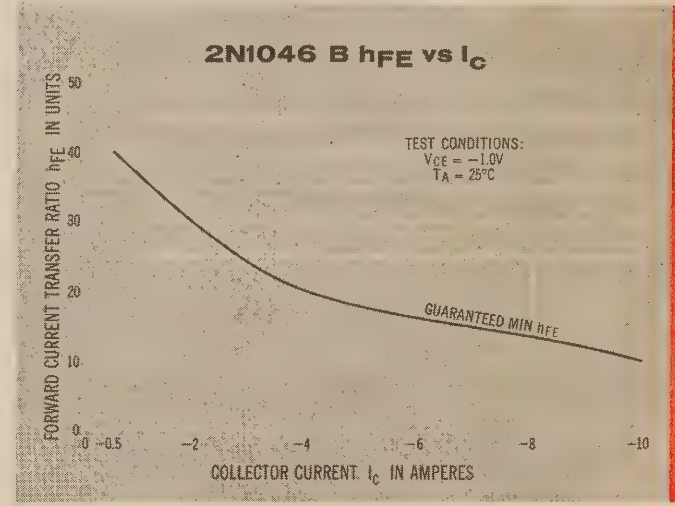
MANIUM POWER TRANSISTORS

New high current 2N1046-A-B give you high frequency/dissipation/voltage with high beta!



New TI 2N1046B germanium power transistors give you 10 amp I_C with typical 18 mc f_T* . . . 130 volt BV_{CBO} . . . guaranteed beta of 10 at 10 amp I_C . . . 30 watt dissipation . . . high frequency/high current operating characteristics. The 2N1046 series alloy-diffused P-N-P transistors provides maximum reliability for your core driving, hi-fi amplification, and other high frequency power applications.

f_T Frequency at which common emitter current gain of the device is unity.*

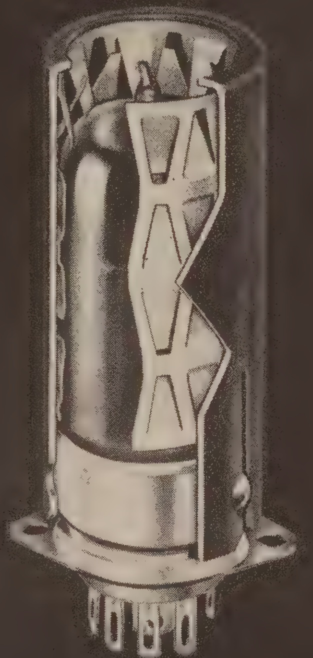


Call on your nearest TI distributor or sales office for immediate delivery of TI germanium power transistors including the 1-amp 2N1038 series and the 3-amp 2N1042 series power transistors.

TI GERMANIUM POWER TRANSISTOR CHARACTERISTICS AT 25°C

Type	Dissipation at 25°C watts	Collector to Base Voltage-v max	Collector to Emitter Voltage min BV_{CEO}	Emitter to Base Voltage-v min BV_{EBO}	Collector Current Amps max	h_{FE} @ I_c		Collector Reverse Current I_{CO} max		Typ R_{CS} @ I_c ohms	Internal Cutoff Frequency avg f_T
						min	max	ma	v		
2N456A	50	−40	−20	−20	−7	30 @ 5a	90	−0.5	−20	0.040 @ 5a	430 kc
2N457A	50	−60	−30	−20	−7	30 @ 5a	90	−0.5	−30	0.040 @ 5a	430 kc
2N458A	50	−80	−40	−20	−7	30 @ 5a	90	−0.5	−40	0.040 @ 5a	430 kc
2N1021	50	−100	−50	−20	−7	30 @ 5a	90	−0.5	−50	0.040 @ 5a	430 kc
2N1022	50	−120	−50	−20	−7	30 @ 5a	90	−0.5	−60	0.040 @ 5a	430 kc
2N511	80	−40	−20	−30	−25	20 @ 10a	60	−2	−20	0.025 @ 10a	260 kc
2N511A	80	−60	−30	−30	−25	20 @ 10a	60	−2	−30	0.025 @ 10a	260 kc
2N511B	80	−80	−40	−30	−25	20 @ 10a	60	−2	−40	0.025 @ 10a	260 kc
2N512	80	−40	−20	−30	−25	20 @ 15a	60	−2	−20	0.033 @ 15a	280 kc
2N512A	80	−60	−30	−30	−25	20 @ 15a	60	−2	−30	0.033 @ 15a	280 kc
2N512B	80	−80	−40	−30	−25	20 @ 15a	60	−2	−40	0.033 @ 15a	280 kc
2N513	80	−40	−20	−30	−25	20 @ 20a	60	−2	−20	0.038 @ 20a	300 kc
2N513A	80	−60	−30	−30	−25	20 @ 20a	60	−2	−30	0.038 @ 20a	300 kc
2N513B	80	−80	−40	−30	−25	20 @ 20a	60	−2	−40	0.038 @ 20a	300 kc
2N514	80	−40	−20	−30	−25	20 @ 25a	60	−2	−20	0.040 @ 25a	350 kc
2N514A	80	−60	−30	−30	−25	20 @ 25a	60	−2	−30	0.040 @ 25a	350 kc
2N514B	80	−80	−40	−30	−25	20 @ 25a	60	−2	−40	0.040 @ 25a	350 kc
2N1038	20	−40	−30	−20	−3	20 @ 1a	60	−125μa	−20	0.150 @ 1a	8.0 kc $f_{\alpha e}$ min
2N1039	20	−60	−40	−20	−3	20 @ 1a	60	−125μa	−30	0.150 @ 1a	8.0 kc $f_{\alpha e}$ min
2N1040	20	−80	−50	−20	−3	20 @ 1a	60	−125μa	−40	0.150 @ 1a	8.0 kc $f_{\alpha e}$ min
2N1041	20	−100	−60	−20	−3	20 @ 1a	60	−125μa	−50	0.150 @ 1a	8.0 kc $f_{\alpha e}$ min
2N1042	20	−40	−30	−20	−3	20 @ 3a	60	−125μa	−20	0.167 @ 3a	8.0 kc $f_{\alpha e}$ min
2N1043	20	−60	−40	−20	−3	20 @ 3a	60	−125μa	−30	0.167 @ 3a	8.0 kc $f_{\alpha e}$ min
2N1044	20	−80	−50	−20	−3	20 @ 3a	60	−125μa	−40	0.167 @ 3a	8.0 kc $f_{\alpha e}$ min
2N1045	20	−100	−60	−20	−3	20 @ 3a	60	−125μa	−50	0.167 @ 3a	8.0 kc $f_{\alpha e}$ min
2N1046	30	−100	−50	− 1.5	−10	40 @ 0.5a		−1	−40	0.500 @ 1a	15 mc min
2N1046A	30	−140	−50	− 1.5	−10	20 @ 4a		−1	−40	0.125 @ 4a	15 mc min
2N1046B	30	−140	−50	− 1.5	−10	10 @ 10a		−1	−40	0.050 @ 10a	15 mc min

NOT
NEW,
but...



...proved by millions in use over several years! IERC TR type Heat-dissipating Electron Tube Shields are still the only effective heat-dissipating tube shield designed for retrofitting equipment having JAN bases.

Present TR's are unchanged from the original version introduced—and over the years, nothing has equalled their cooling and retention qualities. The greatly extended tube life and reliability provided by IERC TR's is acknowledged by the entire industry.

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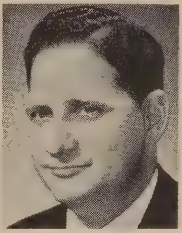
International Electronic Research Corporation
145 West Magnolia Boulevard, Burbank, California

IRE People

(*Continued from page 46A*)

Mr. Burns is a member of Tau Beta Pi, Eta Kappa Nu, Sigma Xi and Phi Kappa Phi. He has authored several classified publications and technical articles in the electronics field.

❖



J. G. Anderson

Jack G. Anderson (A'56) has been appointed vice president for government relations at Stromberg-Carlson, Vice President and General Manager Allan R. Shilts has announced. Stromberg-Carlson is a division of General Dynamics Corporation.

Mr. Anderson comes to Stromberg-Carlson from Hoffman Electronics Corporation of Los Angeles, where he was vice president for marketing. He had been with Hoffman since 1954, first as manager of Air Force operations and later as director of military marketing.

From 1942 to 1954 he served with the U. S. Air Force in many assignments throughout the United States, Europe, Africa and the Pacific. He was a major when discharged.

Mr. Anderson attended the University of Louisville and received the B.S. degree from the USAF Institute of Technology in Dayton, Ohio.

He is a past president of the Dayton Wright Chapter of the Armed Forces Communications and Electronics Association and is a member of many other organizations, including the American Rocket Society, Institute of Aeronautical Sciences, Air Force Association, Air Traffic Control Association, American Ordnance Association, Association of the U. S. Army, and the Navy League.

❖

Ralph J. Bahnsen (S'54-A'55–M'59), has been promoted to the position of advisory engineer in the Systems Engineering Department of Advanced Computational Systems at the IBM Product Development Laboratory in Poughkeepsie, N. Y. He is in charge of analysis work on an advanced Data Processing System.

He joined the company in June, 1954 as a technical engineer working on the 702 Computer. He was transferred to Kingston in 1955 and returned to Poughkeepsie in 1956, attaining the status of associate engineer. He was engaged in the 738 memory and logical design of an advanced data processing system. He became a staff engineer in 1958, his position until his recent promotion.

Mr. Bahnsen attended Queens College and received the B.E.E. degree from the College of the City of New York in 1954.

❖

Dr. Nicholas A. Begovich (S'41–A'48–M'58), has been appointed assistant man-

(*Continued on page 54A*)

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TRANSISTOR
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ADVANCED DESIGN POWER TRANSISTORS FROM CLEVITE

Three new lines of germanium power transistors by Clevite feature new advances in controlled gain spread, fully specified collector-to-emitter voltage characteristics and low current leakage — even at maximum voltages and high temperatures.

The new 8 ampere switching series can be used to replace the older, more costly ring-emitter types in 3 to 8 ampere service.

The new 25 ampere switching type offers exceptionally low saturation voltage and is available with either pin terminals or solder lugs.

The new Spacesaver design not only affords important savings in space and weight, but its significantly improved frequency response means higher audio fidelity, faster switching and better performance in regulated power supply applications. Its low base resistance gives lower input impedance for equal power gain and lower saturation resistance, resulting in lower "switched-on" voltage drop. Lower cut off current results in better temperature stability in direct coupled circuits and a higher "switched-off" impedance.

CLEVITE NOW OFFERS THESE COMPLETE LINES

Switching Types	Amplifier Types
5 ampere	2 watt
8 ampere	4 watt
15 ampere	2 watt Spacesaver
25 ampere	
3 ampere Spacesaver	

All Clevite germanium power transistors are designed for low thermal resistance, low base input voltage, low saturation voltage and superior current gain.

For latest data and prices or application assistance, write for Bulletin 60 . . .

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CLEVITE TRANSISTOR

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$\dot{v} = \frac{F}{m} - \frac{\rho v^2 d^2 C_D}{2m} - g\phi$
$\dot{\phi} = -\frac{g}{v}(1-\phi^2)\left[1-\frac{v^2}{gR}\right]$
$G\frac{dT_s}{dt} = h(T_g - T_s) - \sigma\epsilon T_s^4$
$I = \sqrt{\frac{RT_c}{g_0}}\left[\frac{F_e}{F_t}\sqrt{2(\gamma+1)} - \frac{P_a A_e}{P_c A_t}\right.$

ENGINEERING TEAMWORK IN SPACE EXPLORATION

Engineers and scientists interested in a wide range of activities will appreciate the advanced nature of research and development projects under way at JPL. These projects include research, basic and applied, in Electronics, Solid State Physics, Propulsion, Aerodynamics, Structures and Materials and the design, development and analysis of space probes and satellites. Individually responsible engineers and scientists work together as a thoroughly integrated team in accomplishing the complete objective.

Programs involve guidance, telemetering, data recording and reduction, instrumentation, structures, propulsion, materials, solid state physics, components, heat transfer problems and systems analysis and are constantly influenced by continuing JPL space exploration research providing individuals with challenging assignments in almost every phase of engineering and science. Staff progress in diverse fields of activity is constantly being made.

Pioneering in basic research, applied research and development engineering in space exploration proves to be a stimulating attraction for engineers and scientists with innate curiosity and intense interest in the future of space exploration.

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Employment opportunities for Engineers and Scientists interested in basic and applied research in these fields:

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Send professional resume, with full qualifications and experience, for our immediate consideration

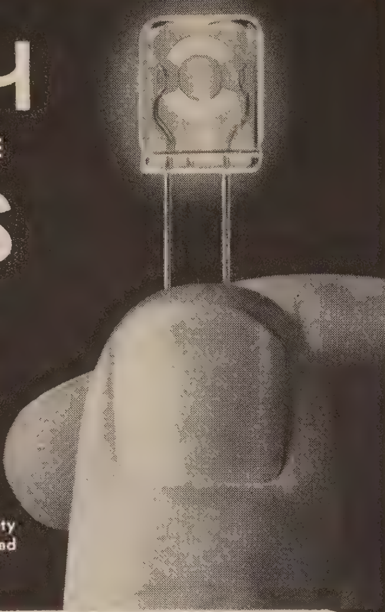
McCOY

G-20 & G-21 MINIATURE

ALL-GLASS

HC-18/U TYPE

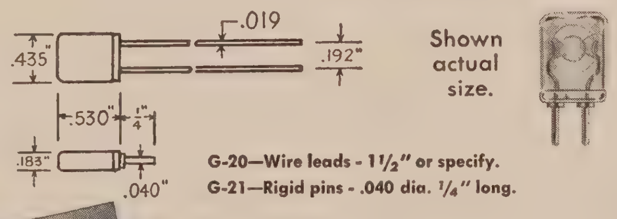
CRYSTAL UNITS



Possess all of the quality and dependability for which the McCoy line of metal encased crystal units is famous.

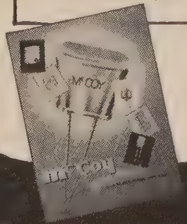
Check these advantages:

- ✓ Excellent Long-Term Stability
- ✓ Minimum Aging
- ✓ Choice of Leads — Pins or Flexible Wire
- ✓ Maximum Resistance to Shock and Vibration 30 vector G's from 20 to 2000 cps — vibration 100 G's — shock
- ✓ True Hermetic Seal Altitude is no problem
- ✓ Meets new CR-73/U and CR-74/U Specs
- ✓ Wide Range of Frequencies Available 5000 KC to 200,000 KC
- ✓ Extremely Small Size



Shown actual size.

G-20—Wire leads - 1½" or specify.
G-21—Rigid pins - .040 dia. ¼" long.



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Dept. P-5
MT. HOLLY SPRINGS, PA.
Phone HUnter 6-3411

(Continued from page 50A)

ager of Hughes Aircraft Company's Ground Systems Group, C. Harper Brubaker, vice president and Group manager, has announced.

N. A. Begovich

Dr. Begovich, formerly director of engineering at the Hughes plant, also will serve as director of product line operations.

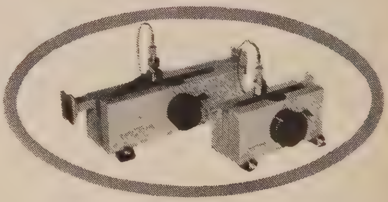
He developed the principle of radar frequency scanning which, as incorporated in Hughes' "Frescanar," provides pinpoint three-dimensional information (range, bearing and altitude) using only one antenna, one transmitter and one receiver. Frescanar is the "eyes" of Missile Monitor, an advanced mobile air defense developed by Hughes for the U. S. Army.

Joining Hughes as a research physicist in 1948, he has also served as a consultant to the weapons system evaluation group for the Department of Defense, as a research engineer for the War Metallurgy Committee and the War Production Board, and as an instructor in electrical engineering at California Institute of Technology.

(Continued on page 56A)

STANDING WAVE DETECTORS

—*exceptionally accurate*



You get the accuracy that results from perfect parallelism between slot and waveguide axis . . . between probe travel and waveguide axis. Only 30 seconds needed to equip a D-B slotted line to measure adjacent frequency bands. Range: 5.8 KMC to 140 KMC—covered by a *minimum* of units, to stretch your budget. Literature on request.

DE MORNAY BONARDI

DE MORNAY—BONARDI
780 SOUTH ARROYO PARKWAY • PASADENA, CALIF.

Distributed constant delay lines • Lumped-constant delay lines • Variable delay networks • Continuously variable delay lines • Pushbutton decade delay lines • Shift registers •

ESC EXTRA

Pulse transformers • Medium and low-power transformers • Filters of all types • Pulse-forming networks • Miniature plug-in encapsulated circuit assemblies

---

ESC DEVELOPS DELAY LINE WITH 170 to 1 DELAY TIME/ RISE TIME RATIO

Model 61-34 Perfected
For Specialized
Communications Application

PALISADES PARK, N. J.—An entirely new Lumped-Constant Delay Line, with a proven 170 to 1 delay time/rise time ratio, has been announced by the ESC Corporation, Palisades Park, N. J. The new delay line, known as Model 61-34, was specifically designed for a specialized communications application calling for the exceptionally high delay time/rise time ratio.

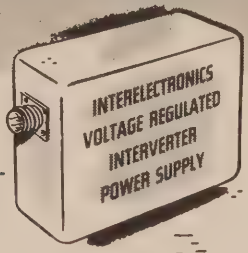
ESC, the world's leading manufacturer of custom built and stock delay lines, is already widely recognized in the electronics industry for its exceptional engineering advances. In October, 1958, ESC broke through an existing design barrier and produced a delay line with a 145 to 1 delay time/rise time ratio. It had been thought, prior to the announcement of the Model 61-34, that ESC had reached the ultimate in this type of delay line.

SPECIFICATIONS OF NEW DELAY LINE
MODEL 61-34

Delay time/rise time ratio: 170/1
Delay: 200 usec.
Rise time: 1.16 usec.
Attenuation: less than 2 db
Frequency response: 3 db = 325 KC
50 taps with an accuracy of ±0.2 usec. at each tap.

Complete technical data on the new unit can be obtained by writing to **ESC Corporation, 534 Bergen Boulevard, Palisades Park, New Jersey.**

PROVEN RELIABILITY—
SOLID-STATE POWER INVERTERS
over 260,000 logged hours— voltage-regulated, frequency-controlled, for missile, telemeter, ground-support, 135°C all-silicon units available now—



Interelectronics all-silicon thyratron-like gating elements and cubic-grain toroidal magnetic components convert DC to any desired number of AC or DC outputs from 1 to 10,000 watts.

Ultra-reliable in operation (over 260,000 logged hours), no moving parts, unharmed by shorting output or reversing input polarity. Wide input range (18 to 32 volts DC), high conversion efficiency (to 92%, including voltage regulation by Interelectronics patented reflex high-efficiency magnetic amplifier circuitry).

Light weight (to 6 watts/oz.), compact (to 8 watts/cu. in.), low ripple (to 0.01 mv. p-p), excellent voltage regulation (to 0.1%), precise frequency control (to 0.2% with Interelectronics extreme environment magnetostrictive standards or to 0.0001% with fork or piezoelectric standards).

Complies with MIL specs. for shock (100G 11 mlsc.), acceleration (100G 15 min.), vibration (100G 5 to 5,000 cps.), temperature (to 150 degrees C), RF noise (I-26600).

AC single and polyphase units supply sine waveform output (to 2% harmonics), will deliver up to ten times rated line current into a short circuit or actuate MIL type magnetic circuit breakers or fuses, will start gyros and motors with starting current surges up to ten times normal operating line current.

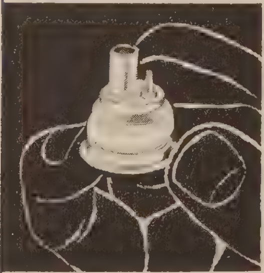
Now in use in major missiles, powering telemeter transmitters, radar beacons, electronic equipment. Single and polyphase units now power airborne and marine missile gyros, synchros, servos, magnetic amplifiers.

Interelectronics—first and most experienced in the solid-state power supply field produces its own all-silicon solid-state gating elements, all high flux density magnetic components, high temperature ultra-reliable film capacitors and components, has complete facilities and know how —has designed and delivered more working KVA than any other firm!

For complete engineering data, write Interelectronics today, or call LUdlow 4-6200 in New York.

INTERELECTRONICS CORPORATION
2432 Grand Concourse, New York 58, N. Y.

SEAL PROBLEMS? A CASE IN POINT



PROBLEM:
GENERAL ELECTRIC required development of a rugged compact high current hermetic seal CONTROLLED RECTIFIER housing constructed of materials and processes to withstand temperatures above soft solder range—design involves 5 seals to dissimilar materials.

SOLUTION:
Mechanical requirement dictated use of 3 metals: alloy #52, OFHC and Gr "A" Ni. Braze material selected is above 1435°F. so that subsequent welding or brazing can be done without detrimental effect. Tapered seals eliminate costly ground ceramics.

CERAMIC TO METAL ASSEMBLIES BY MITRONICS ARE:
• More precise • More compact • More economical • More durable

Why struggle with metallizing problems when Mitronics' complete engineering facilities are at your disposal.

METALLIZING SPECIALISTS
Write, phone or wire for technical assistance, information

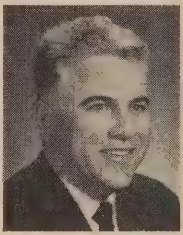
mitronics inc.
1292 Central Ave., Hillside, N. J., WAverly 6-2250

IRE People

(Continued from page 54A)

Dr. Begovich received the B.S., M.S. and Ph.D. degrees from Caltech. He has published papers on high frequency vacuum tube theory, electro-magnetic radiation problems and radar detection theory.

❖


C. W. BURROWS JR.

Carl W. Burrows, Jr., (M'59), has been appointed director of headquarters sales at Stromberg-Carlson Division of General Dynamics Coporation, according to an announcement by Allan R. Shilts, vice president and general manager of the division.

Mr. Burrows comes to Stromberg-Carlson from Hoffman Electronics Corporation where he was associated with the military products division as director of headquarters sales. Prior to this he was with the Bendix-Pacific Division of Bendix Aviation Corporation.

From 1943 to 1955 he was on active duty with the Navy. For two and a half years during this time he served as an instructor at the U. S. Naval Postgraduate School, Monterey, Calif. in communications and anti-submarine warfare. He resigned from the Navy in 1955 as a lieutenant commander.

He attended Pasadena City College and was graduated from the U. S. Naval Academy at Annapolis, Md., in 1943. He is also a graduate of the communications course at the U. S. Naval Postgraduate School, Annapolis.

He is a member of the Institute of Aeronautical Sciences and the American Rocket Society.

❖

Solomon Charp (A'43–M'44–SM'50), has been appointed Manager of Navigation and Control Electronic Equipment for General Electric's Missile and Space Vehicle Department, Philadelphia, Pa.

He is responsible for three basic functions: investigation of complete navigation and control electronic systems; design and development of control components such as sensors and computers; and the design of electronic circuitry.

He joined the company in July, 1959, as a Consultant in radiation and data comparison and electronic systems. For eleven years previous to that he was a member of the research staff of The Franklin Institute.

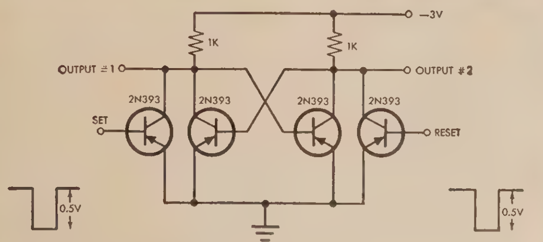
A native of Jersey City, N. J., he attended public schools in Philadelphia. He graduated from the University of Pennsylvania, Philadelphia, in 1940 with the B.S. degree in Electrical Engineering and received the M.S. degree from that university in 1941.

He was an instructor and research associate at the University of Pennsylvania for seven years previous to joining

(Continued on page 58A)

PHILCO MAT* TRANSISTORS are UNIVERSALLY APPLICABLE

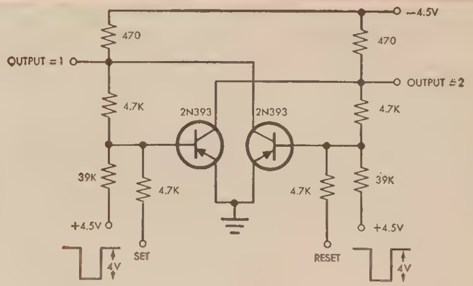
To All Logic Circuits Up To 5mc



−3V
1K
1K
OUTPUT = 1
OUTPUT #2
2N393
2N393
2N393
2N393
SET
RESET
0.5V
0.5V

DIRECT COUPLED TRANSISTOR LOGIC FLIP-FLOP

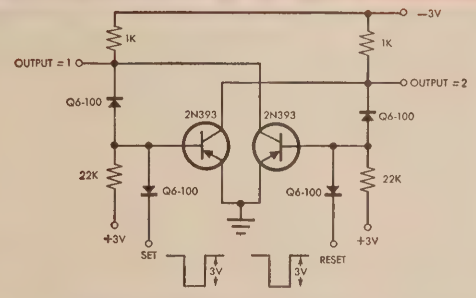
TYPICAL SWITCHING TIMES: t_r=12 mμsec. t_f=15 mμsec.



−4.5V
470
470
OUTPUT = 1
OUTPUT #2
4.7K
4.7K
2N393
2N393
39K
39K
4.7K
4.7K
+4.5V
+4.5V
SET
RESET
4V
4V

RESISTOR COUPLED TRANSISTOR LOGIC FLIP-FLOP

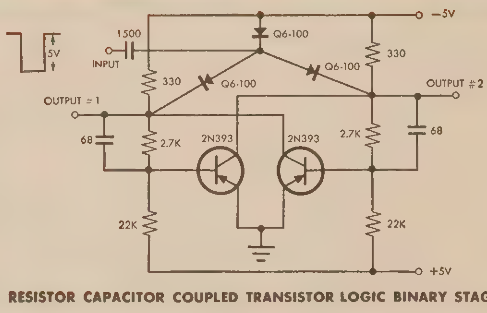
TYPICAL SWITCHING TIMES: t_r=40 mμsec. t_f=110 mμsec.



−3V
1K
1K
OUTPUT = 1
OUTPUT = 2
Q6-100
Q6-100
2N393
2N393
22K
22K
Q6-100
Q6-100
+3V
+3V
SET
RESET
3V
3V

DIODE COUPLED TRANSISTOR LOGIC FLIP-FLOP

TYPICAL SWITCHING TIMES: t_r=20 mμsec. t_f=60 mμsec.



−5V
1500
5V
INPUT
Q6-100
Q6-100
Q6-100
330
330
OUTPUT = 1
OUTPUT #2
68
68
2.7K
2.7K
2N393
2N393
22K
22K
+5V

RESISTOR CAPACITOR COUPLED TRANSISTOR LOGIC BINARY STAGE

TYPICAL SWITCHING TIMES: t_r= 30 mμsec. t_f= 44 mμsec.

high frequency performance...at medium frequency prices

2N393

The Philco 2N393 Micro Alloy Transistor (MAT) has proved its complete reliability in millions of operating hours in every type of computer logic circuit up to 5 mc. It combines all the advantages of high frequency performance with low price. The 2N393 is easily designed into any logic circuit and offers the designer these important advantages:

- High beta
- Low saturation voltage
- High speed
- High V_{BE} rating
- Low I_{CO}
- Low hole storage time

When you can buy so much for so little . . . don't settle for less in *your* equipment.

The 2N393 is also available in a military version . . . Mil 5-19500/77A (Sig.C.)

Other Philco MATs to Meet Your Special Requirements:

2N1122 . . . with 11 volt rating
2N1122A . . . with 14 volt rating
2N1427 . . . with additional parameter control

For data sheets, write Department IR 560.

*Reg. U.S. Pat. Off.

Immediately available in quantities 1-999 from your local Philco Industrial Semiconductor Distributor.

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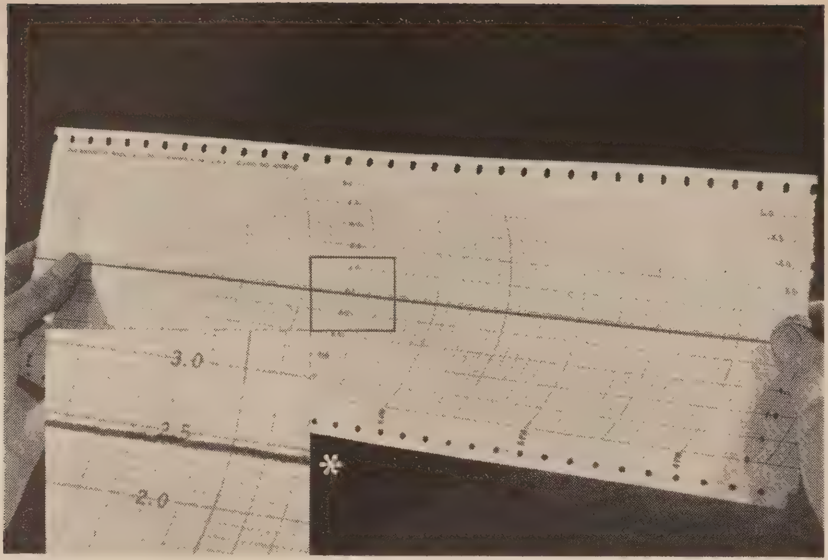
TRANSISTOR CENTER U.S.A.



*Measure fractions of a microvolt...*approaching the Johnson noise limit... with Beckman DC Breaker Amplifiers. These high gain, low drift amplifiers are insensitive to vibrations, provide fast response and feed outputs directly to standard recorders. This means you can measure dc and low frequency ac voltages which were impossible or too tedious with devices like suspension galvanometers. A few applications include use with ultra-precision bridge circuits for measurement of differential thermocouples, nerve voltages, and other extremely low voltages. For detailed specifications write for Data File 9-5-11.

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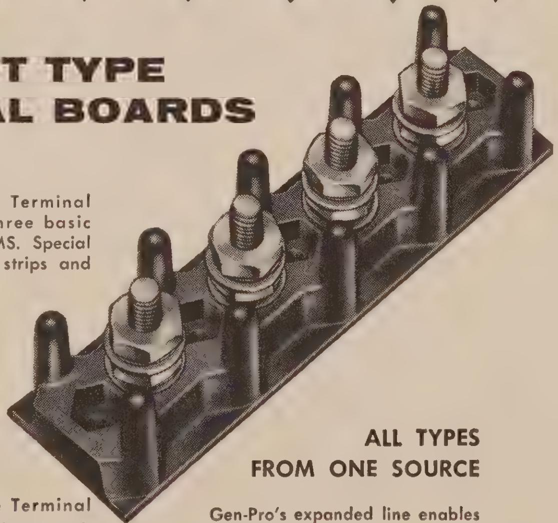
INSTRUMENTAL IN YOUR FUTURE 25 YEARS 1935-1960

**Note low noise level...less than .003 microvolt*

new GEN-PRO®

AIRCRAFT TYPE TERMINAL BOARDS

New series of Molded Terminal Boards available in three basic types—AN, NAS and MS. Special compoundings, backing strips and hardware on request.



ALL TYPES FROM ONE SOURCE

Gen-Pro Aircraft Type Terminal Boards — soon available through distributors. Sales and service reps in key U. S. cities. Fast delivery.

WRITE NOW FOR FURTHER DETAILS

Gen-Pro's expanded line enables you to order all types of Terminal Boards from a single source; standard military, commercial, and others for special applications.

GENERAL PRODUCTS CORPORATION
Over 25 Years of Quality Molding
UNION SPRINGS, NEW YORK TWX No. 169

IRE People

(Continued from page 56A)

The Franklin Institute in 1948.

He has conducted research in naval anti-aircraft fire control systems, electromechanics, statistical-type analogue computers, radar reflections, and radar guidance systems.

Mr. Charp is a member of Tau Beta Pi, Pi Mu Epsilon, Sigma Xi, the Research Society of America, and the AIEE. He is a member of the Executive Board of the Philadelphia Section of the AIEE and serves as Treasurer, 1960 International Solid State Circuits Conference.

❖

L. Berkley Davis (SM'53), has been elected a vice-president of the General Electric Company. He is general manager of the company's electronic components division which is made up principally of the Receiving Tube Department (Owensboro, Ky., also site of division headquarters); the Cathode Ray Tube Department (Syracuse, N. Y.); the Power Tube Department (Schenectady, N. Y.); and the Semiconductor Products Department (Syracuse, N. Y.)

L. B. Davis

He was born in Lewisport, Ky., October 27, 1911, and graduated from high school there. He attended the Engineering College of the University of Kentucky at Lexington, a member of the class of 1934.

After starting work in 1934 as an engineer with the former Ken-Rad Tube and Lamp Corporation in Owensboro, Ky., subsequent advancements placed him in charge of tube production engineering and brought him the position of chief engineer for the Ken-Rad Transmitting Tube Corporation. During World War II he became plant manager of the Owensboro Transmitting Tube operation. General Electric acquired the Ken-Rad tube facilities on January 2, 1945, and near the end of that year Mr. Davis was made manager of the Owensboro operations.

In December, 1949 he was appointed general manager of General Electric Receiving Tube operations, with headquarters in Owensboro. He became general manager of the newly-created Electronic Components Division of the General Electric Company in June, 1956, and retains this position with his appointment as a vice-president of the company.

❖

Warren C. Foin (S'53–A'54), has been promoted to the position of development engineer in the 7080 Engineering Department of Advanced Data Systems Development at the IBM Product Development Laboratory in Poughkeepsie, N. Y. He is now project manager, responsible for the design of the IBM 7080 Data Processing System.

(Continued on page 60A)

RMC

SUBMINIATURE

DISCAPS

DESIGNED FOR COMPACT PRODUCTS

SPECIFICATIONS

POWER FACTOR: 1.5% Max. @ 1 KC (initial)

WORKING VOLTAGE: 500 V.D.C.

TEST VOLTAGE (FLASH): 1000 V.D.C.

LEADS: No. 22 tinned copper (.026 dia.)

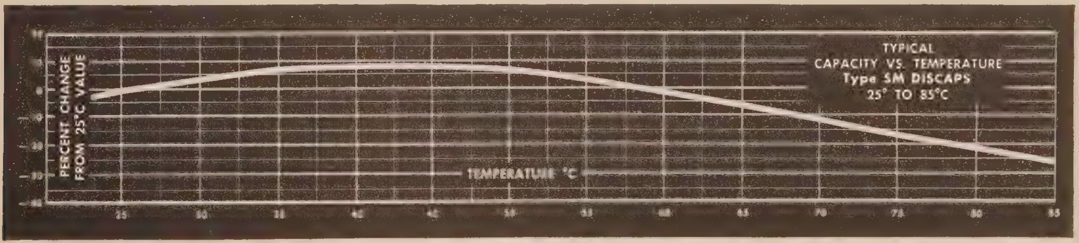
INSULATION: Durez phenolic (1/8″ max. on leads)—vacuum waxed

STAMPING: RMC—Capacity—Z5U

INITIAL LEAKAGE RESISTANCE: Guaranteed higher than 7500 megohms

AFTER HUMIDITY LEAKAGE RESISTANCE: Guaranteed higher than 1000 megohms

RMC Type SM DISCAPS are designed for applications in compact radios, testing products, communication equipment and other products where space is of prime importance. These DISCAPS are rated at a working voltage of 500 volts and exhibit a minimum capacity change between +10° and +85° C. Type SM DISCAPS can be specified with the complete assurance of quality and reliability that is inherent in all RMC DISCAPS.



DISCAP
CERAMIC
CAPACITORS

RMC

RADIO MATERIALS COMPANY
A DIVISION OF P. R. MALLORY & CO., INC.
GENERAL OFFICE: 3325 N. California Ave., Chicago 18, Ill.
Two RMC Plants Devoted Exclusively to Ceramic Capacitors

FACTORIES AT CHICAGO, ILL. AND ATTICA, IND.

"... Where there is no air
to resist their motions,
all bodies will move with the greatest freedom."

SIR ISAAC NEWTON *Principles of Natural Philosophy*

Today, almost three hundred years after Newton's *Principia* appeared, man is about to satisfy his centuries-old curiosity concerning space "where there is no air." First instruments went. Soon man himself will go.

Prior to man's undertaking sustained space voyages propulsion systems with efficiencies far exceeding those presently available must be developed.

The scientists and engineers at Electro-Optical Systems are in the advanced stages of research and development on what may well be a forerunner of practical space propulsion systems — the ion engine.

Other advanced research and development programs in areas vital to technological progress in space, military weaponry and industry include:

Energy Conversion Research and Advanced Power Systems
Heat Rejection in Space
Molecular Electronics
Optical Tracking and Guidance
Space Communications Systems
Exploding Wire Research

EOS has professional opportunities for Physicists, Mathematicians and Engineers.

E
ELECTRO-OPTICAL SYSTEMS, INC. O 125 NORTH VINEDO AVE.
S PASADENA, CALIFORNIA

IRE People

(*Continued from page 58A*)

Mr. Foin joined IBM in December, 1950 as a customer engineer and became a technical engineer on the IBM 770 in 1954. He has subsequently held positions as associate engineer and project engineer, his position until his recent advancement. Prior to his affiliation with the Company, Mr. Foin was associated with the Chance Vought Division of United Aircraft.

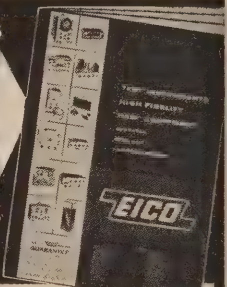
Mr. Foin received B.S.M.E. degrees from the Universities of New Hampshire and Illinois in 1945 and 1947 respectively, and the M.S.M.E. degree from Columbia University, New York, N. Y., in 1950. He is a member of Pi Tau Sigma.

⁂

Steve J. Gadler (SM'59), Col. USAF (Ret.), has been elected a Vice President of Hitchcock & Estabrook, Inc., Consulting Engineers and Architects. Mr. Gadler, who is director of the firm's newly established Electronic Division, is a graduate of the University of Minnesota in Electrical Engineering, is a registered professional engineer, and is considered an authority in Electronic Communications Systems Engineering.

He was decorated with the Legion of Merit for his outstanding contributions in the Communications Electronic field while he was Director of Electronics for

(*Continued on page 64A*)



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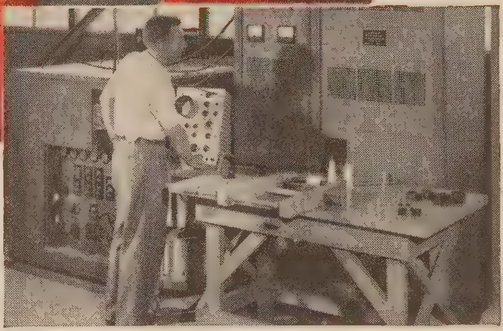
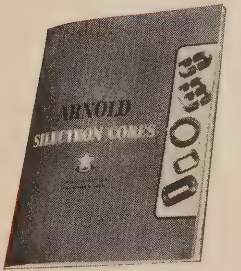


7372 C

Arnold Pulse Transformer Cores are individually tested under actual pulse conditions

Here's technical data on

ARNOLD SILECTRON CORES



Bulletin SC-107 A . . . this newly-reprinted 52-page bulletin contains design information on Arnold Tape Cores wound from Silectron (grain-oriented silicon steel). It includes data on cut C and E cores, and uncut toroids and rectangular shapes. Sizes range from a fraction of an ounce to more than a hundred pounds, in standard tape thicknesses of 1, 2, 4 and 12 mils.

Cores are listed in the order of their power-handling capacity, to permit easier selection to fit your requirements, and curves showing the effect of impregnation on core material properties are included. A valuable addition to your engineering files—*write for your copy today.*

ADDRESS DEPT. P-5

The inset photograph above illustrates a special Arnold advantage: a 10-megawatt pulse-testing installation which enables us to test-prove pulse cores to an extent unequalled elsewhere in the industry.

For example, Arnold 1 mil Silectron "C" cores—supplied with a guaranteed minimum pulse permeability of 300—are tested at 0.25 microseconds, 1000 pulses per second, at a peak flux density of 2500 gausses. The 2 mil cores, with a guaranteed minimum pulse permeability of 600, receive standard tests at 2 microseconds, 400 pulses per second, at a peak flux density of 10,000 gausses.

The test equipment has a variable range which may enable us to make special tests duplicating the actual operating conditions of the transformer. The pulser permits tests at .05, .25, 2.0 and 10.0 microsecond pulse duration, at repetition rates varying anywhere from 50 to 1000 pulses per second.

This is just another of Arnold's facilities for better service on magnetic materials of all description. ● Let us supply *your* requirements. *The Arnold Engineering Company, Main Office & Plant, Marengo, Ill.*

ARNOLD
SPECIALISTS in MAGNETIC MATERIALS

BRANCH OFFICES and REPRESENTATIVES in PRINCIPAL CITIES
Find them FAST in the YELLOW PAGES

When it comes to SEMICONDUCTORS

For the most **complete** line of solid state devices...

- Westinghouse has perfected the widest selection of rectifiers, transistors, and special semiconductor devices available in the industry. In Silicon power rectifiers, Westinghouse is the acknowledged leader in the field.

For the most **dependable** semiconductor devices...

- Every Westinghouse semiconductor device has been carefully designed, manufactured, and thoroughly tested to assure long life, high reliability, and excellent stability.

For **true voltage ratings** in silicon power transistors...

- Only Westinghouse 2N1015 and 2N1016 silicon power transistors offer *true* voltage ratings, guaranteed by 100% power testing—means they may be operated continuously at the V_{CE} listed provided the power dissipation of the transistor is not exceeded. Other conventional power transistors derate the V_{CE} voltage under comparable conditions.

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- Westinghouse is constantly pioneering in exciting new semiconductor devices. Among the latest: a new 50 ampere "TRINISTOR"* controlled rectifier; new thermoelectric cooling devices; an extremely rapid and sensitive infrared detector.

For quality, reliability, performance, and availability...

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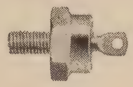
YOU CAN BE SURE...IF IT'S Westinghouse

Westinghouse Semiconductor Department, Youngwood, Pa.

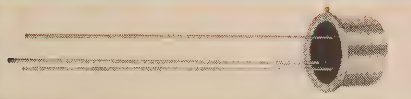
*Westinghouse Trademark

COME TO WESTINGHOUSE!

SILICON RECTIFIERS

			P.R.V.	Max. DC Current at T°C Resistive Load	Max. One Cycle 60 C.P.S. Surge Full Load	Max. Rev. Peak Current @ Max. Temp. & P.I.V.
LOW POWER RECT.		1N1217 SERIES	50-1000 V.	500 MA @ 110°C. AMB.	15 AMPS.	1.5 MA @ 150°C. JUNCTION
		1N1227 SERIES	50-1000 V.	1.6 A @ 140°C. CASE	15 AMPS.	
MEDIUM POWER RECT.		1N1341 SERIES	50-600 V.	6 A @ 150°C. CASE	160 AMPS.	10 MA @ 190°C. JUNCTION
		1N1199 SERIES	50-600 V.	12 A @ 150°C. CASE	200 AMPS.	
		1N1191 SERIES	50-600 V.	18 A @ 140°C. CASE	220 AMPS.	
		1N1183 SERIES	50-600 V.	35 A @ 140°C. CASE	220 AMPS.	
HIGH POWER RECT.		1N1396 SERIES	50-500 V.	70 A @ 150°C. CASE	1200 AMPS.	30 MA @ 190°C. JUNCTION
		1N1660 SERIES	50-500 V.	160 A @ 125°C. CASE	2000 AMPS.	40 MA @ 190°C. JUNCTION
		1N1670 SERIES	50-500 V.	240 A @ 125°C. CASE	3000 AMPS.	50 MA @ 190°C. JUNCTION
		439 SERIES	50-600 V.	240 A @ 125°C. CASE	3000 AMPS.	

GERMANIUM TRANSISTORS

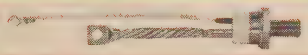


	Class	Typical Operation			Maximum Ratings			
		I_{CBO} μa	h_{FE}	f mc/s	V_{CE} V	I_C ma	P_C mw	T_J °C
2N59	AUDIO-PNP	10	100	1.2	20	200	180	85
2N60	AUDIO-PNP	10	70	1.1	20	200	180	85
2N403	AUDIO-PNP	10	33	0.85	20	200	180	85
2N614	IF -PNP	3	5	3	20	150	125	85
2N616	IF -PNP	3	20	9	20	150	125	85
2N617	IF -PNP	3	14	7	20	150	125	85

SILICON POWER TRANSISTORS

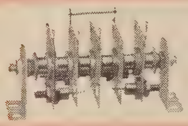
	Type	h_{fe} or h_{FE}	$f_{\alpha mc}$	V_{CEX} Volts	I_C Amps	T_J °C
2N1015 SERIES—2 AMP.	NPN	10 (V_{CE}=4 V I_C=2 A)	ALPHA CUTOFF .300	30-200	7.5a	150
2N1016 SERIES—5 AMP.	NPN	10 (V_{CE}=4 V I_C=5 A)	ALPHA CUTOFF .300	30-200	7.5a	150

50 AMPERE SILICON "TRINISTOR" CONTROLLED RECTIFIER



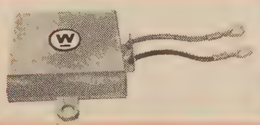
Breakover Voltage @ 125°C T_J	Reverse Blocking Voltage @ 125°C T_J	Turn-on Time	Turn-off Time
TYPICAL			
50-200 VOLTS	50-200 VOLTS	1.0 μ SEC.	15-20 μ SEC.

RECTIFIER ASSEMBLIES



Standard rectifier assemblies are available in all types of circuit configurations, and are designed for either forced air or natural convection cooling with a wide range of ratings. Nickel-plated copper plates and other materials used in these assemblies have been chosen to insure satisfactory performance in corrosive atmospheres and high ambient temperatures.

THERMOELECTRIC COOLING DEVICES



Two types are available in commercial quantities: WX814 (2.5 oz.) and WX816 (3.0 oz.). Both types measure about an inch and a half square and will find immediate application in cooling germanium transistors, infrared detectors, optical systems, mechanical and electric instruments, laboratory and portable medical equipment, and related fields where spot cooling below ambient is necessary.

INFRARED DETECTORS

Type	Noise Equivalent Power (NEP) Watts	Wave-length Response. Microns	Time Constant, μ SEC.
812	TYPICAL LIMIT 5x10^{-11} 10^{-10} MAX.	1-12	TYPICAL LIMIT 0.1 0.2 MAX.

The types listed are just a small sampling of the complete line which can be supplied in volume quantities for prompt deliveries.

Now Available for the First Time...

SAGE
SILICOHM
S10W—1%
43000 Ω

SAGE RESISTORS

with The Amazing New Moisture-Resistant

"IMPERVOHM" silicone coating

WHAT IS "IMPERVOHM"? . . . It is a new non-porous silicone encapsulant representing a significant moisture seal "break through," which has been developed exclusively for SAGE Characteristic "G" and "V" Power Resistors.

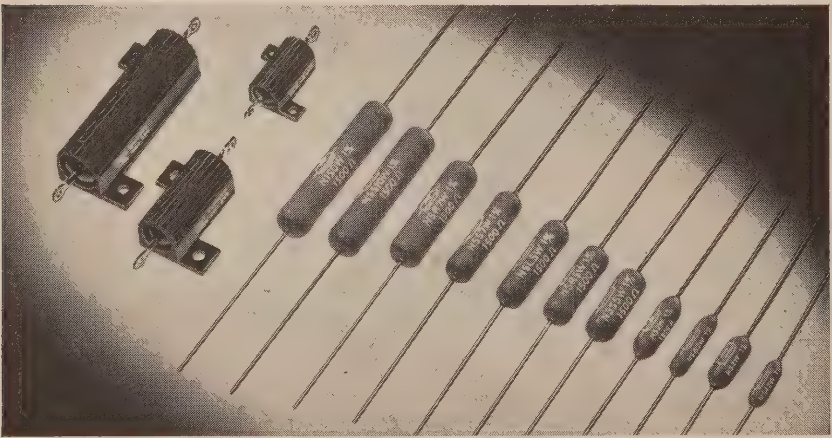
WHAT ARE ITS ADVANTAGES? . . . Because of its unusual characteristics attributed to optimum balance of resin and precise filler particles, this new coating requires no compromise in offering:

- Improved heat endurance (−65°C to +350°C).
- Superior resistance stability (0.1%) after severe moisture cycling.
- Availability of all type "S" Resistors as reliable body insulated styles (1000 Volts rms min.).
- New ruggedness in ultrasonic solvent wash not previously available.

These features signify an insulating achievement unmatched in the power resistor field.

WHERE DO SAGE "IMPERVOHM"-SEALED RESISTORS EXCEL? Component and Circuit Design Engineers will be wise to specify SAGE in all applications demanding critical sensitiveness to moisture and temperature extremes. They will also take advantage of the insulation ruggedness these Resistors offer for printed circuit assembly as well as for metal chassis contact mounting. Of special significance in all cases is long life environment protection.

YOU PAY NO PREMIUM FOR "IMPERVOHM" PROTECTION . . . This remarkable coating is now "Standard" on SAGE Resistors—conventionally wound types "S" and "CS" and non-inductively wound types "NS" and NCS."



Write for samples and engineering data

SAGE ELECTRONICS CORPORATION
COUNTRY CLUB ROAD · EAST ROCHESTER, N. Y.

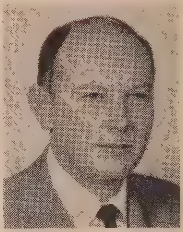
IRE People

(Continued from page 60A)

the Air Defense Command Headquarters at Colorado Springs, Colo.

He is the author of many articles on technical matters and has several electronic developments to his credit. Mr. Gadler is a member of the American Institute of Electrical Engineers the Minnessota Society of Professional Engineers, the National Society of Professional Engineers, the North St. Anthony Park Business Men's Association and a Senior member of the Institute of Radio Engineers. He has been officially commended by the Norwegian and Japanese Governments for his work in Electronics.

❖



A. C. Hall

Dr. Albert C. Hall (A'39–SM'46–F'58), director of research and engineering for The Martin Company, has been named the company's vice president of engineering, George M. Bunker, chairman of the board, has announced.

Dr. Hall was elected by the missile, electronic and nuclear firm's board of directors at its regular monthly meeting last Friday. He will make his

(Continued on page 66A)

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- AMATEUR and CAP
- AIRLINE and AVIATION
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- MILITARY and MISSILE USE

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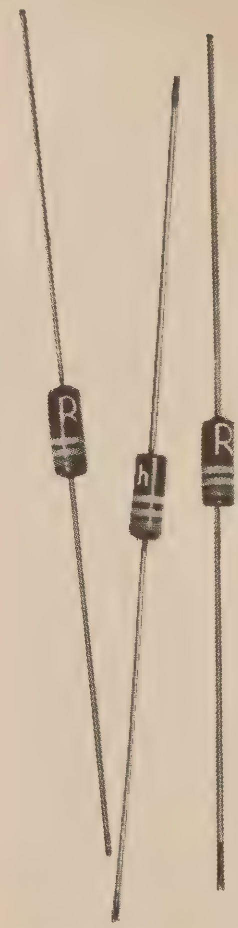
15 advanced types including IN903 through IN908: IN251 • IN914 • IN916



These new Millimicrosecond Diodes feature:

RECOVERY TIME

.004 μsec.

VERY LOW CAPACITANCE

1 μμf @ —6 volts

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CIRCUIT BREAKER

ACTUAL SIZE

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SERIES 500

POSITIVE PROTECTION

Available in series, shunt and relay types, Airpax Miniature Magnetic Circuit Breakers are stocked in DC, 60 and 400 CPS models. Current ratings are from 0.05 to 10 amperes. Trip action can be instantaneous or delayed depending on the circuit requirement. These Circuit Breakers are also available in 2 and 3 gang assemblies, in any combination, for interlock-circuit protection.

Ask for Bulletins B-07 and B-16

AIRPAX ELECTRONICS INCORPORATED

CAMBRIDGE DIVISION CAMBRIDGE, MARYLAND

(Continued from page 64A)

headquarters in Denver, Colo.

Since joining Martin in 1958, his major effort has been with the TITAN program. Martin is prime contractor for airframe design, fabrication and testing of the weapon system.

A leading guidance and control systems scientist, he was general manager of the Bendix Aviation Corporation's Research Laboratories Division, Detroit, before he came to Martin as research director. He became engineering director for the TITAN in January, 1959.

The new vice president founded the Dynamic Analysis and Control Laboratory at the Massachusetts Institute of Technology, where he was a faculty member for 13 years.

A native of Port Arthur, Texas, where he was born on June 27, 1914, Dr. Hall earned the B.S. degree in electrical engineering from Texas A. & M. in 1936. He received the M.S. degree in 1938 and the D.Sc. degree in 1943, both from M.I.T.

He joined the M.I.T. faculty in 1937 as associate professor of electrical engineering. He founded and became the first director of the Dynamic Analysis and Control Laboratory in 1946.

While at M.I.T., he helped to develop missile control design techniques and directed the control system design effort for the World War II BAT, the first successful Navy air-to-surface guided missile.

As laboratory director, he supervised the development of the first missile simulator. He also was a Martin consultant for the Navy VIKING high altitude research rocket.

He left M.I.T. in 1950 to become associate director of the Bendix Research Laboratories Division. He was named division technical director in 1952 and general manager two years later. At Bendix, he directed research and development of electronic and hydraulic controls, including guidance and control systems for several guided missiles and automatic machine tool controls.

He was a member of the first Automation Exchange group sent to Russia in 1955 under the auspices of the American Society of Mechanical Engineers.

Dr. Hall holds the Naval Ordnance Development Award and the Eta Kappa Nu Outstanding Young Electrical Engineer Award. He is a member of Tau Beta Pi, Sigma Xi and several engineering societies.

⁂

Cecil S. Bidlack (A'35–VA'39–SM'55), of Smith Electronics, Inc. and formerly of the National Association of Educational Broadcasters has joined the firm of Carl E. Smith Consulting Radio Engineers, Brecksville, Ohio. He will be responsible for consulting work in Television and FM broadcast.

His last assignment was with the sister firm of Smith Electronics, Inc., where as

(Continued on page 68A)

Other type numbers in the RHEEM Mesa line: 2N497, 2N498, 2N696, 2N697, 2N656, 2N657, 2N699, 2N1252, 2N1253, 2N1420

another RHEEM FIRST!

NEW SILICON MESA ½ AMP. FAST SWITCHING TRANSISTORS

RT5001 RT5002 RT5003 RT5004

SPECIFY RHEEM FOR RELIABILITY

Rheem

RHEEM'S new High Current Switching transistors feature:

LOW SATURATION VOLTAGE

1.5 volts @ 500 mA

HIGH COLLECTOR CURRENT

1 amp

CORE SWITCHING

0.1 μsec.

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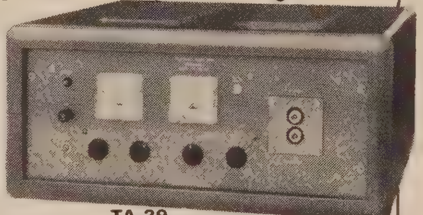

TA-29

The use of permanent magnet focused tubes in Menlo Park Engineering's microwave amplifiers represents a significant improvement over units using solenoid focused tubes . . . and results in three important advantages:

- Lighter weight
- More Compact
- Less power consumption

Frequency	Model No.
0.5- 1.0 KMC	TA-36
1.0- 2.0 KMC	TA-31
2.0- 4.0 KMC	TA-29
4.0- 8.0 KMC	TA-28
8.2-11.0 KMC	TA-20
10.0-16.0 KMC	TA-49

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MENLO PARK ENGINEERING
711 Hamilton Avenue Menlo Park, Calif. DAvenport 6-9080

IRE People

(Continued from page 66A)

Supervisor of Systems Engineering he was charged with the design of audio and control circuitry for the Consolidated East Coast Facilities sites of the Voice of America at Greenville, North Carolina. With the NAEB at Urbana, Illinois, Mr. Bidlack served as engineering advisor to the executive director of the association.

Mr. Bidlack's affiliations include the Society of Motion Picture and Television Engineers, the American Institute of Electrical Engineers and the Audio Engineering Society. He is a registered Professional Engineer in the State of Ohio and holds radiotelephone first-class and amateur radio class "A" licenses.

❖

Donald C. Bright (SM'49), formerly a division sales manager with Radio Corporation of America, has been appointed general manager of the new Industrial Electronics Division of Hoffman Electronics Corp.

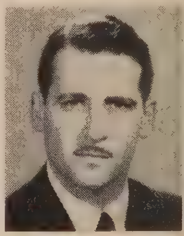
D. C. Bright

Before joining Hoffman, he was with RCA nine years and most recently was manager of government contracts and sales for its West Coast missile and surface radar division in Los Angeles.

Mr. Bright's earlier experience included assignments as chief engineer of Liberty Manufacturing Co., Youngstown, Ohio; chief of the radio control section for the U. S. Air Force, Wright Field, Dayton, Ohio; and sales engineer with Westinghouse.

❖

Earl H. Flath, Jr., (A'44–M'54), has joined Temco Electronics division of Temco Aircraft Corporation as a senior scientist to plan developments in the fields of radiation, antennas and microwave systems.



E. H. Flath, Jr.

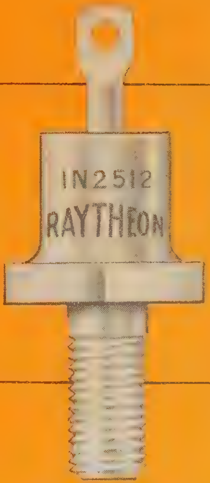
He was graduated from Southern Methodist University with honors in 1943 and received the M.S. Degree from the University of Cincinnati. He also studied at the University of Maryland.

He served as an electronic scientist with the Naval Research Laboratory and as senior aerophysics engineer with Convair prior to joining Chance Vought in 1952. With the latter company, he served in various supervisory positions in the fields of antenna development and electronics systems design, and finally as engi-

(Continued on page 72A)

1N536
RAYTHEON

LOW POWER. Consider the high-efficiency Raytheon 1N536 series.



MEDIUM POWER. Look into the Raytheon 1N253 and the new 1N2512 series.

Raytheon diffused junction (upper photo) gives utmost uniformity, highest performance, greatest reliability. Compare with irregular fusion junction (below).

HIGH POWER. Note the all-new Raytheon 1N248A, 1N1191A and 1N1195 series.

For reliable power . . .

Depend on diffused junction rectifiers!

Here are reliable Raytheon diffused junction silicon rectifiers spanning the complete semiconductor power spectrum!

Raytheon manufacturing success in diffused junction rectifiers has long provided fast recovery, low forward voltage drop and extreme uniformity of device characteristics. Outstanding mechanical design and production under stringent quality control result in rectifiers with excellent ratings and characteristics. Utmost reliability is assured by constant life and environmental testing beyond the most stringent requirements of Mil 19500B, over the guaranteed temperature range of −65°C. to +165°C.

Of special interest in low current applications of the 1N536 series are the excellent reverse recovery, fast start and fast rise of Raytheon diffused junction rectifiers.

In the four amp range, the Raytheon 1N2512 series features low reverse current and is available in three package styles: with insulated stud, stud connected to anode, or stud connected to cathode.

In the higher current range, the new Raytheon diffused junction silicon rectifiers offer ratings up to 22 amps (at 150°C.)—plus the important advantages of low forward voltage drop and high efficiency, for exceptional regulation in power applications.

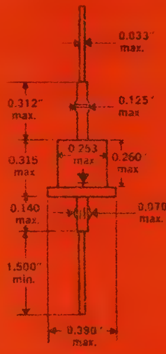
Further information on all these reliable Raytheon rectifiers is given on the following page. Semiconductor Division, Raytheon Company, 215 First Avenue, Needham Heights 94, Massachusetts.

RAYTHEON

RAYTHEON SEMICONDUCTORS

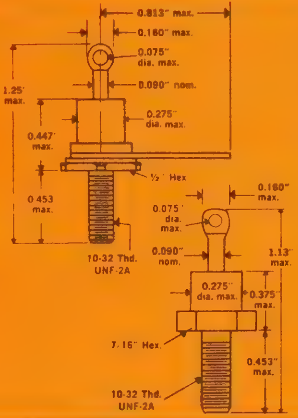
Raytheon diffused junction silicon rectifiers

LOW CURRENT SERIES. The fast reverse recovery, low current Raytheon rectifiers. Feature both fast start and fast rise. Temperature range —65°C. to +165°C.


0.033" max.
0.312" max.
0.125" max
0.253 max
0.260" max
0.315 max
0.140 max.
0.070" max.
1.500" min.
0.390" max.

Type	P.I.V.	Ave. Rectified Current 25°C mA	Ave. Rectified Current 150°C mA	Reverse Current (Max.) in µA at rated P.I.V. 25°C	Reverse Current (Max.) in µA at rated P.I.V. 150°C
1N536	50	750	250	2	400
1N537	100	750	250	2	400
1N538	200	750	250	2	300
1N539	300	750	250	2	300
1N540	400	750	250	2	300
1N1095	500	750	250	2	300
1N547	600	750	250	2	300

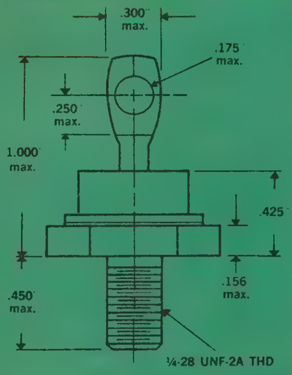
MEDIUM CURRENT SERIES. Workhorse of the Raytheon rectifier line. High efficiency and stability. Insulated or non-insulated stud, standard or reverse polarity. Temperature range —65°C. to +165°C.


0.813" max.
0.160" max.
0.075" dia. max.
0.090" nom.
1.25" max.
0.275" dia. max.
0.447" max.
½" Hex
0.453 max.
10-32 Thd. UNF-2A
0.160" max.
0.075" dia. max.
0.090" nom.
1.13" max.
0.275" dia. max.
0.375" max.
7/16" Hex.
0.453" max.
10-32 Thd. UNF-2A

Cathode to Stud	Anode to Stud	INSULATED Stud	P.I.V. Volts	Ave. Rectified Current 30°C amps.	Ave. Rectified Current 150°C amps.	Reverse Current (max.) µA at rated P.I.V. 25°C	Reverse Current (max.) µA at rated P.I.V. 150°C
1N2512	1N2512R	1N2518	100	4.0	1.0	2.0	250
1N2513	1N2513R	1N2519	200	4.0	1.0	2.0	250
1N2514	1N2514R	1N2520	300	4.0	1.0	2.0	300
1N2515	1N2515R	1N2521	400	4.0	1.0	2.0	300
1N2516	1N2516R	1N2522	500	4.0	1.0	2.0	350
1N2517	1N2517R	1N2523	600	4.0	1.0	2.0	400
1N253			95		1.0*		100*
1N254			190		0.4*		100*
1N255			380		0.4*		150*
1N256			570		0.2*		150*

*At 135°C.

HIGH CURRENT SERIES. The heavy current family of reliable Raytheon rectifiers. Features low forward voltage drop, high efficiency, exceptional regulation. Temperature range—65°C. to +175°C.


.300" max.
.175" max.
.250" max.
1.000" max.
.425"
.450" max.
.156" max.
¼-28 UNF-2A THD

Type	P.I.V.	Ave. Rectified Current, Amps @ 150°C.	Reverse Current (Max.) at Rated P.I.V., mA @ 150°C.
1N248A	50	20	5
1N249A	100	20	5
1N250A	200	20	5
1N1191A	50	22	5
1N1192A	100	22	5
1N1193A	150	22	5
1N1194A	200	22	5
1N1195	300	18	10
1N1196	400	18	10
1N1197	500	18	10
1N1198	600	18	10

J-6949

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RAYTHEON **SEMICONDUCTOR DIVISION** RAYTHEON COMPANY

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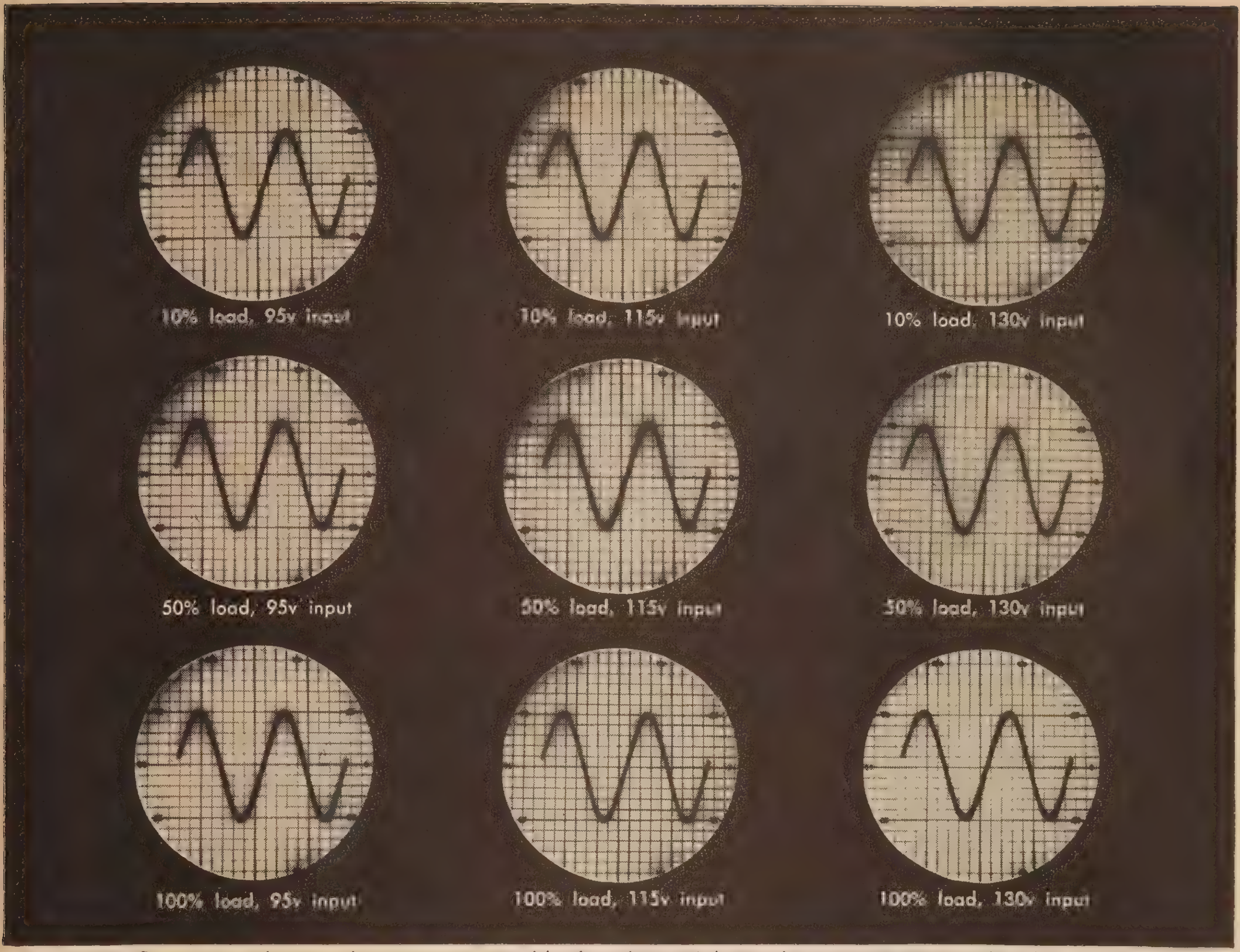


Output wave shapes under varying input and load conditions. Sola Catalog No. 23-13-150 used in this test.

Sola's moderate-cost static-magnetic voltage regulator has sine-wave output

Sola now offers sinusoidal output in every standard-type regulator *with no price premium.* This development — a result of major design and production innovations — greatly widens the field of use for static-magnetic voltage regulation. The new standard sinusoidal design is now ideal for use with electrical and electronic equipment requiring a regulated input voltage with commercial sine wave shape — especially where harmonic-free supply had previously been too costly. The sinusoidal output also contributes to ease of selection and ordering, since this Sola stabilizer is virtually universal in application.

The Sola Standard Sinusoidal Constant Voltage Transformer provides output with less than 3% rms harmonic content. It automatically and continuously regulates output voltage within ±1% for line voltage variations of ±15%. Average response time is 1.5 cycles or less. The new line includes nine stock output ratings from 60va to 7500va.

Besides the improved electrical characteristics, these units are substantially smaller and lighter than previous models. Size and weight reductions were accomplished without any loss of performance or dependability.

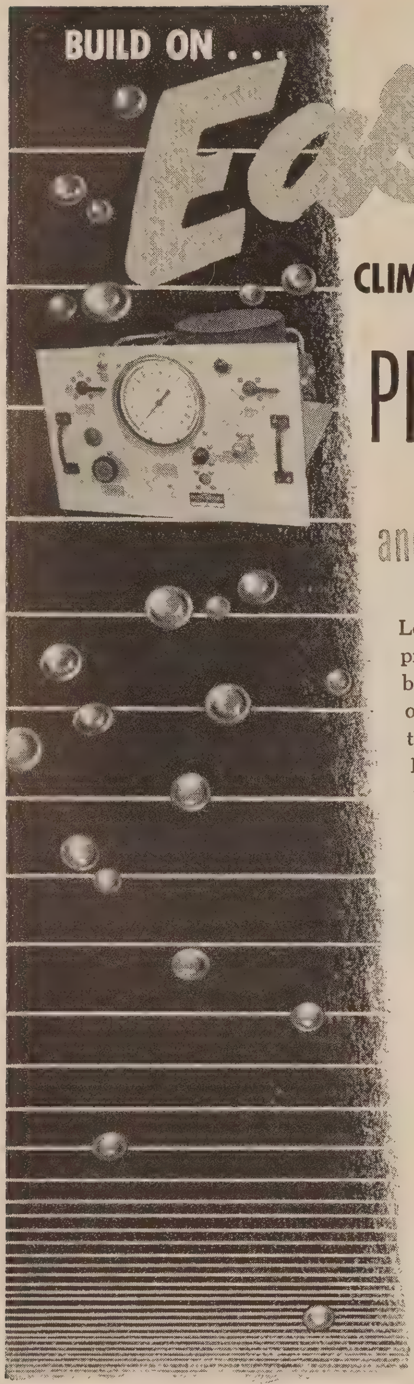
With the Sola Standard Sinusoidal Constant Voltage Transformer you also get all the proved benefits of a static-magnetic regulator. It is simple and rugged. There are no tubes . . . no moving parts . . . no replaceable parts. Maintenance and manual adjustment are not necessary.

Its current-limiting characteristic protects against shorts on the load circuit. It is available in step-up and step-down ratios, allowing substitution for conventional, non-regulating transformers. These units can be used in any electronic or electrical application requiring a regulated sinusoidal power source where the peak power demand does not exceed the capacity of the constant voltage transformer. Circuit design formulae based on sinusoidal wave shape are directly applicable. Custom units to specific requirements are available in production quantities.

Write for Bulletin CVS

SOLA

SOLA ELECTRIC CO.
A Division of Basic Products Corporation
4633 West 16th Street Chicago 50, Illinois



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PRESSURIZATION and DEHYDRATION

Look to Eastern Industries for the advanced pressurization/dehydration packs required by the avionic and ground support systems of tomorrow. Whenever a precisely controlled flow of dehydrated air is required, Eastern design and production experience team up to create compact, lightweight, reliable subsystems. Characteristics and performance range of existing units:

Characteristics and performance range of existing units:

capacities: up to 1.5 FT^3/Min. free air

operating temperatures: from −67°F to +150°F, 100% R.H.

operating altitudes: from 10,000 ft. to 50,000 ft.

weights: from 8 lbs. to 115 lbs. complete

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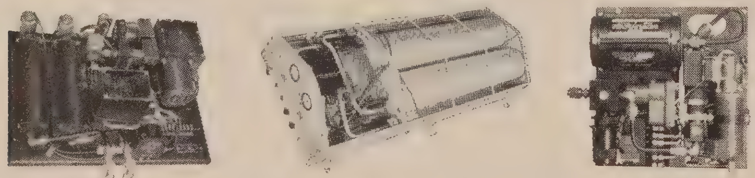

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IRE People

(Continued from page 68A)

neering branch manager in charge of electromagnetic products.

Mr. Flath holds memberships in several professional societies, including the American Institute of Electrical Engineers, Texas Society of Professional Engineers, Sigma Tau and Eta Kappa Nu.

❖

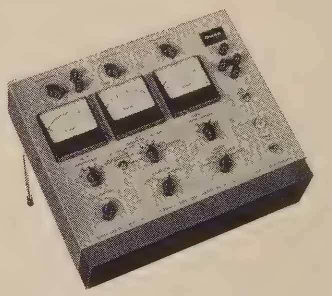
R. Karl Honaman (A'23-SM'44), Director of Publication at Bell Telephone Laboratories, retired on March 1 after more than 40 years of Bell System service.

R. K. Honaman

Since 1945 he had directed all public relations activities of Bell Laboratories, including press relations, employee information, advertising, technical and personnel magazines, technical libraries, and community relations.

A native of Lancaster, Pa., he received the B.S. and M.S. degrees from Franklin and Marshall College in 1916 and 1917, respectively.

(Continued on page 76A)



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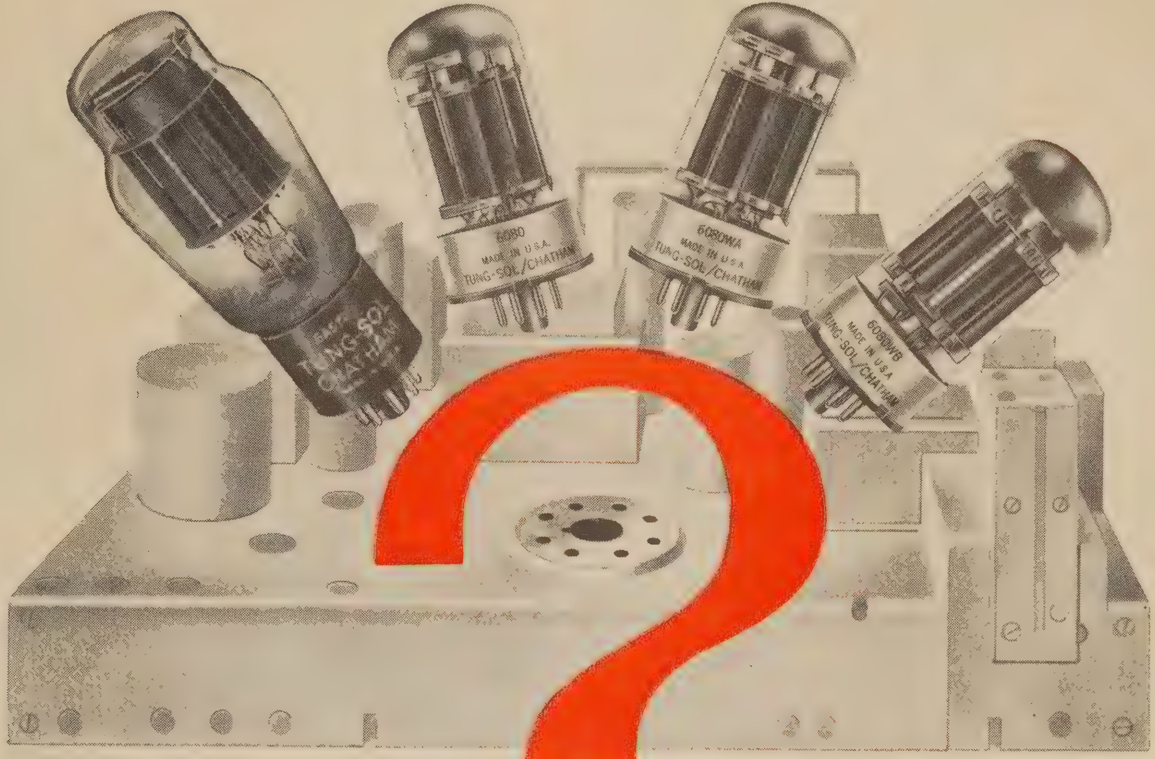

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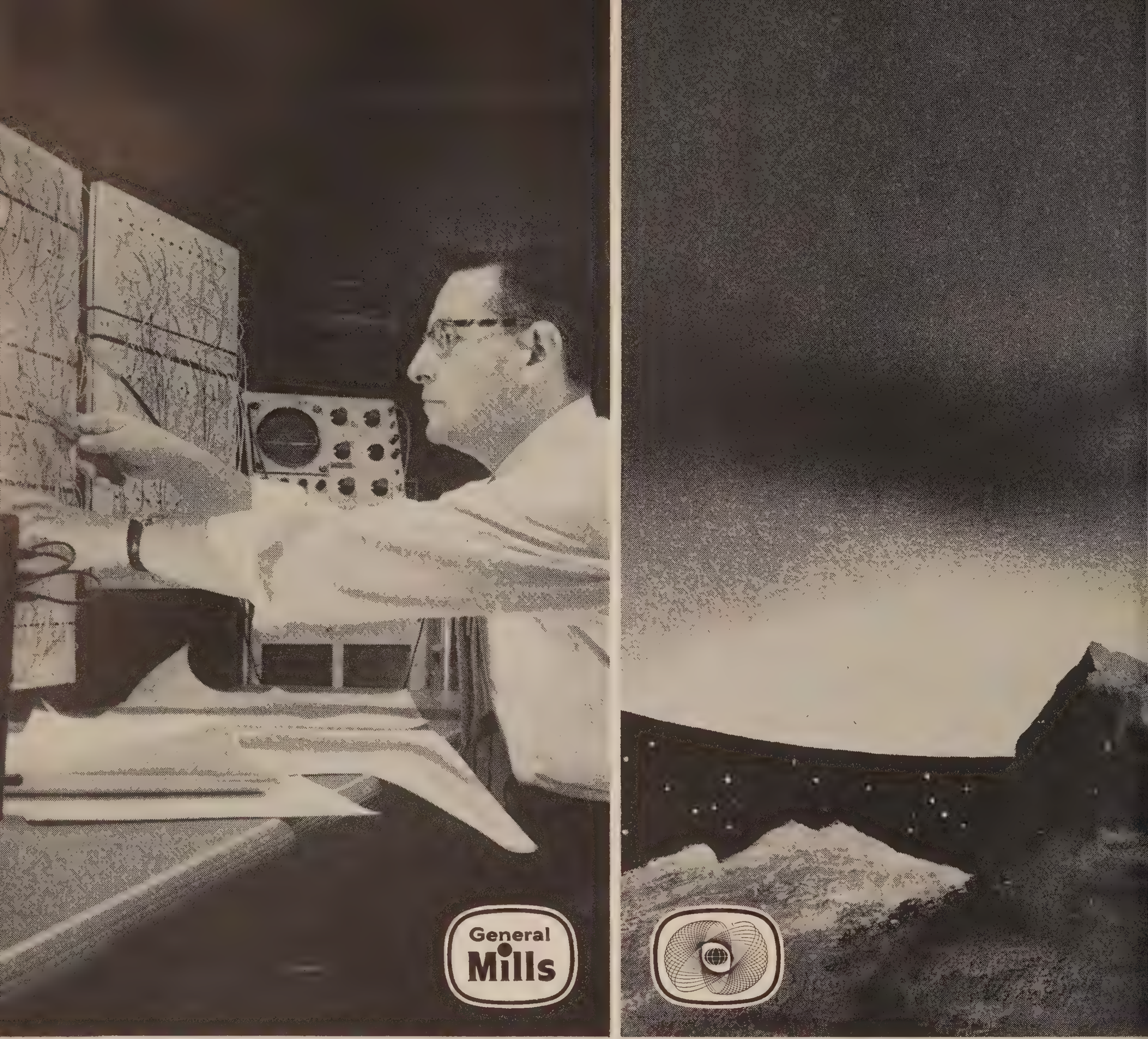

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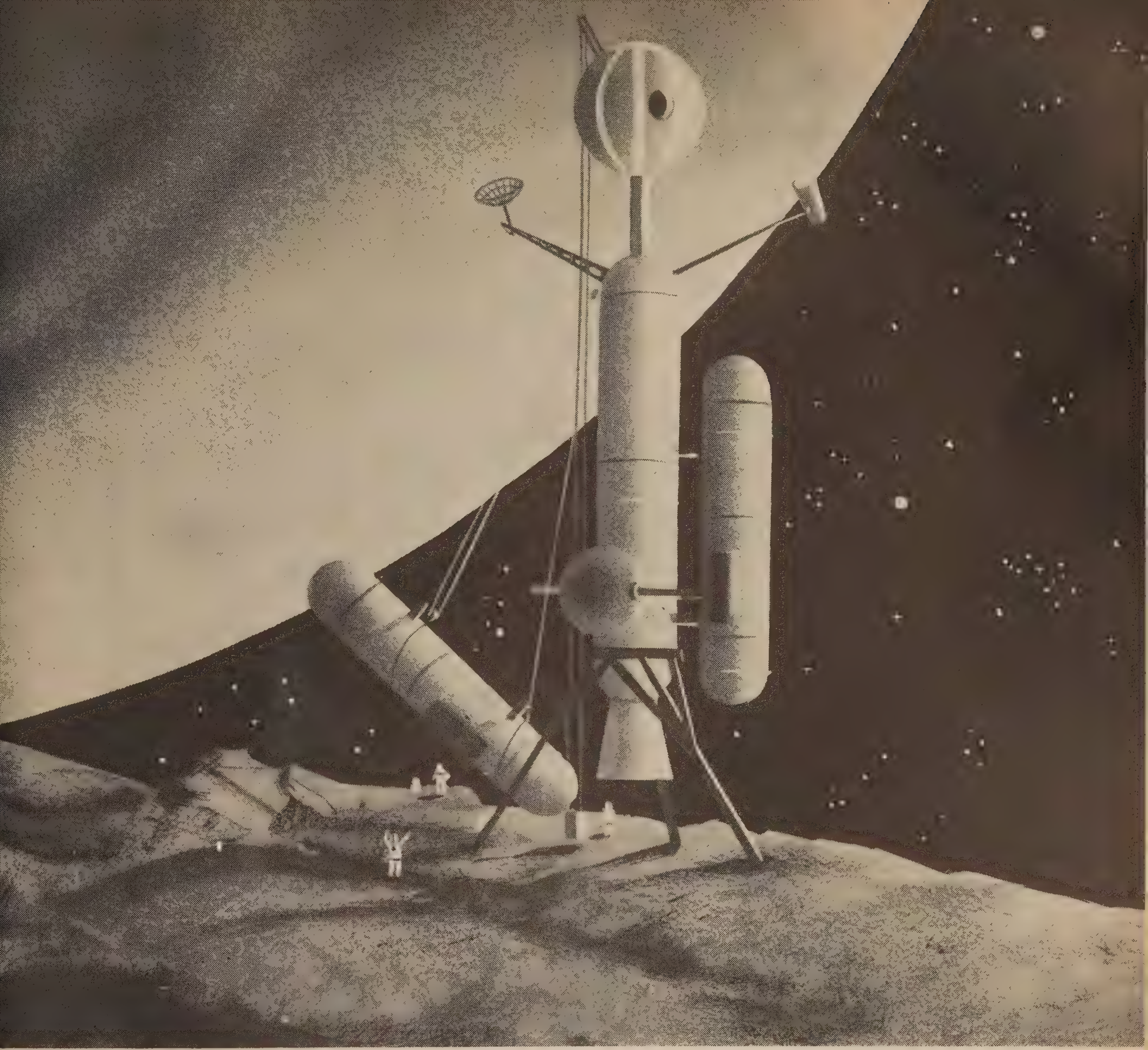

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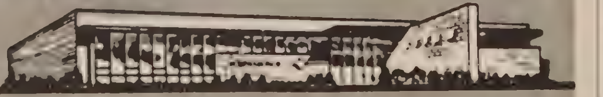

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IRE People

(Continued from page 72A)

He began his telephone career in 1919 with the Development and Research Department of the American Telephone and Telegraph Company in New York. For the next 20 years his work dealt principally with the protection of telephone circuits, and a number of patents were granted to him for inventions in this field. As Assistant Protection Development Engineer, he transferred with his group to Bell Laboratories in 1934.

At the beginning of World War II, and at the request of the Army and Navy, Bell Laboratories instituted its School for War Training to instruct military personnel in radar and related developments. Mr. Honaman organized the school and served as its director until 1945. More than 4,000 officers and men were trained during this period and extensive text material was prepared for the program. At the end of the war, the school had a faculty of almost 100 members.

After the war, he was appointed Director of Publication, with responsibility for all publication and public relations programs of Bell Laboratories.

From October, 1954 to January, 1956, he was on leave from Bell Laboratories to serve with the Federal Government. During the first part of this period he was Consultant to the Secretary of Commerce, and organized and served as Director of the

(Continued on page 80A)

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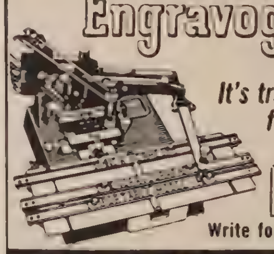

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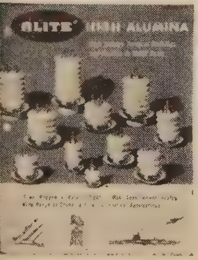

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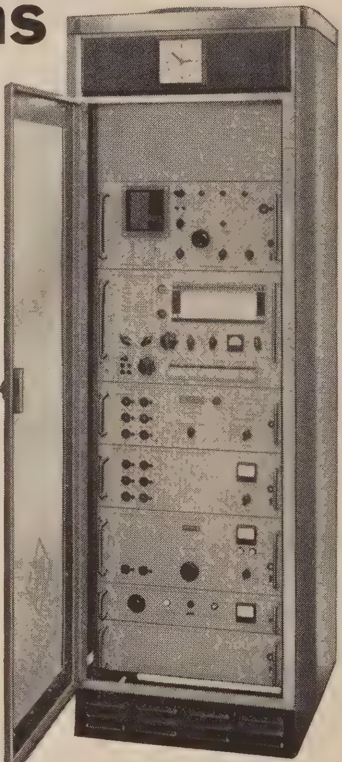

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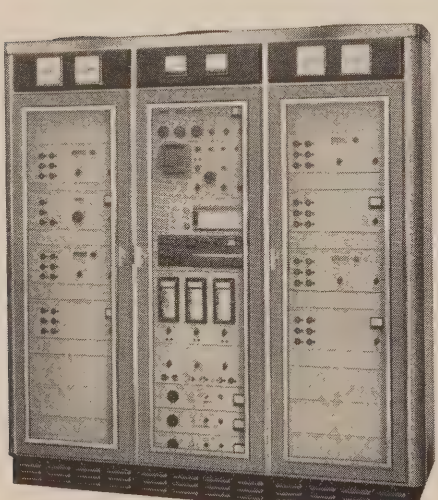

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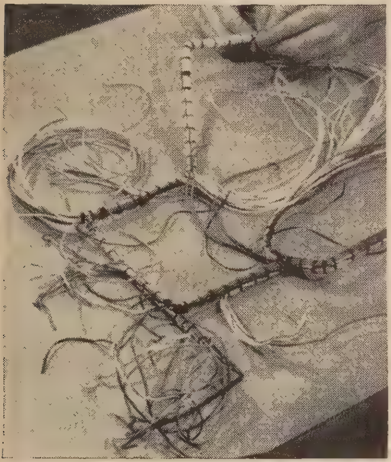

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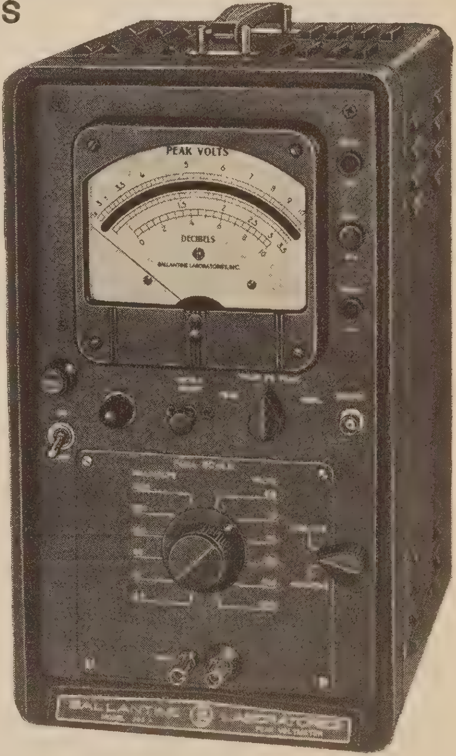

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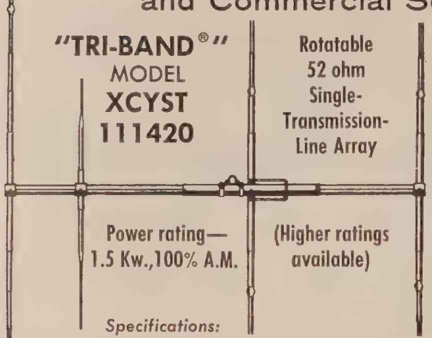

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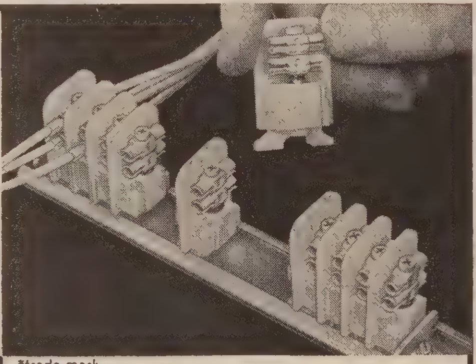

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IRE People

(Continued from page 76A)

Office of Strategic Information. From April to December, 1955, he was Deputy Assistant Secretary of Defense, having responsibility for the public affairs activities of the Defense Department.

He was awarded the 1956 Alumni Citation of Franklin and Marshall College for "outstanding contributions to the greater community." In 1958 he received the Centennial Medal of Seton Hall University.

He is Chairman of the Committee for Engineering Information Services, an Engineers Joint Council sub-committee for cooperation with the National Science Foundation.

He is a Fellow of the American Association for the Advancement of Science and of the American Institute of Electrical Engineers. He is a past president of the New York Electrical Society. He is also a member of the American Management Association, The Society for the Advancement of Management, Public Relations Society of America, Public Relations Society of New York, The Commerce and Industry Association of New York, The New Jersey State Chamber of Commerce, The American Ordnance Association and the Armed Forces Communications and Electronics Association.

He is a director of the Rand Development Corporation, Cleveland, Ohio, of Floating Floors, Inc., New York, N.Y., and of the New Jersey Council on Economic Education.

Mr. Honaman was a member of a delegation which visited Moscow in 1958 to discuss trade relations with the Soviet Union. In 1959 he visited a number of countries of Western Europe, where he discussed industrial and technological problems.

⁂

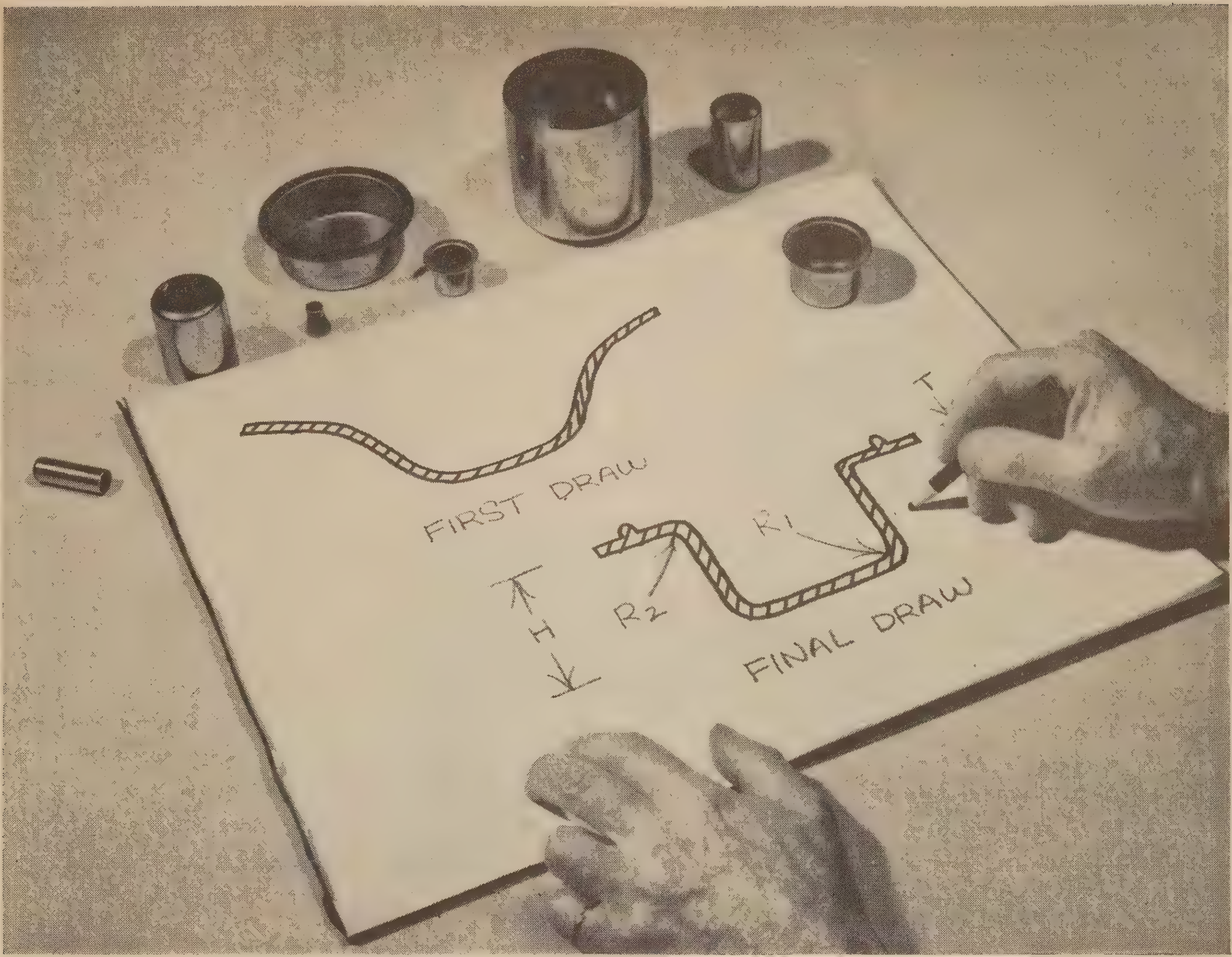
Ark Engineering Company, established in July 1952 as a sole proprietorship under the direction of **Albert R. Kall** (A'49-M'55), announces its incorporation as of January 1, 1960 under the name of Ark Electronics Corporation. The main activities of the company, as before, are consulting engineering specializing in the field of radio interference studies and tests, interference-susceptibility studies of complex weapons and communications systems, custom filter development and production, and custom electromagnetic shielding design. The personnel and policies of the company remain the same. Mr. Kall has been elected president; other executive positions will be announced at a later date.

A. R. Kall

⁂

E. H. Lockhart (A'53–M'56) has been elected Vice-President of R. O. Roberts

(Continued on page 85A)



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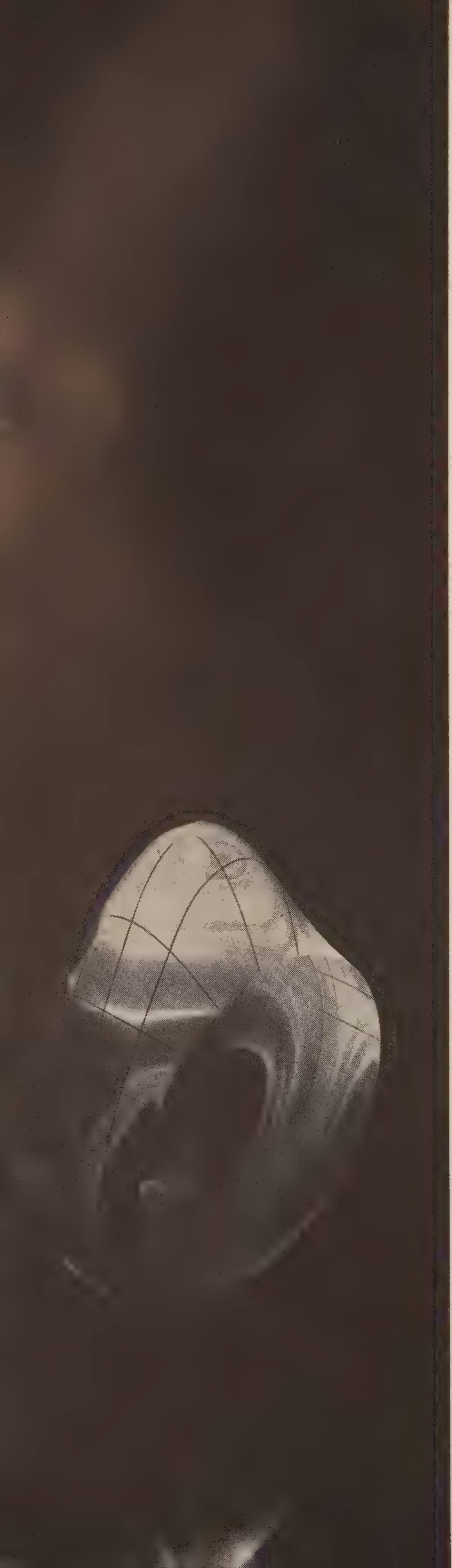

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What goes on when two moving surfaces are separated by a film of oil

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Unfortunately, analytical methods for solving Professor Reynolds' partial differential equation worked only for unrealistic oil bearings bearings with widths approaching zero or infinity. And approximate methods were crude, requiring a complete recalculation for each sligh change in the bearing.

Recently, mathematicians at the General Motors Research Laborato came up with the most versatile and efficient method of solution yet made. Their analytical method for solving the two-dimensiona Reynolds' equation applies to all finite journal bearings — as well a other hydrodynamic bearings — with *no* assumptions or approximatio about boundary locations. The new method uses a long-neglected en theorem recorded by Sir Horace Lamb instead of the force relationshi tried by Reynolds and others.

Besides being a valuable contribution to the theory of lubrication, thi work has its practical side: namely, accurate, serviceable design curves for engineers. At GM Research, we believe delving into both the theoretical and applied sides of a problem is important to progr It is a way of research that helps General Motors fulfill its pledge of "more and better things for more people."

General Motors Research Laboratories

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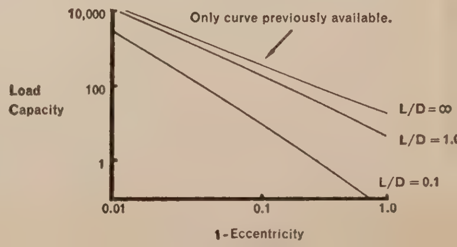
Hydrodynamic analyses have led to specific answers about bearing operation. Shown here are the oil pressure distribution (main illustration) and load-carrying capacity for a non-rotating journal with a reciprocating load.



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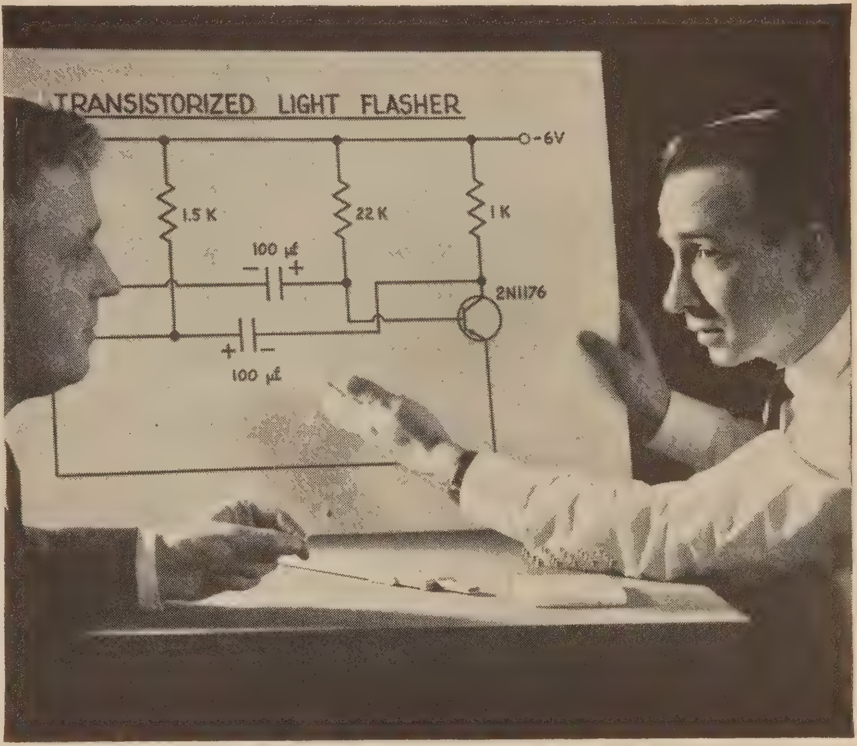

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	Vdc	mAdc	mW	°C	°C	Ic = 10 mAdc		Ic = 100 mAdc Ib = 10 mAdc
2N1008	−20	300	400	85	−65 to +85	90	1.2 mc	0.15 Vdc
2N1008A	−40	300	400	85	−65 to +85	90	1.2 mc	0.15 Vdc
2N1008B	−60	300	400	85	−65 to +85	90	1.2 mc	0.15 Vdc
2N1176	−15	300	300	85	−65 to +85	65	1.2 mc	0.15 Vdc
2N1176A	−40	300	300	85	−65 to +85	65	1.2 mc	0.15 Vdc
2N1176B	−60	300	300	85	−65 to +85	65	1.2 mc	0.15 Vdc

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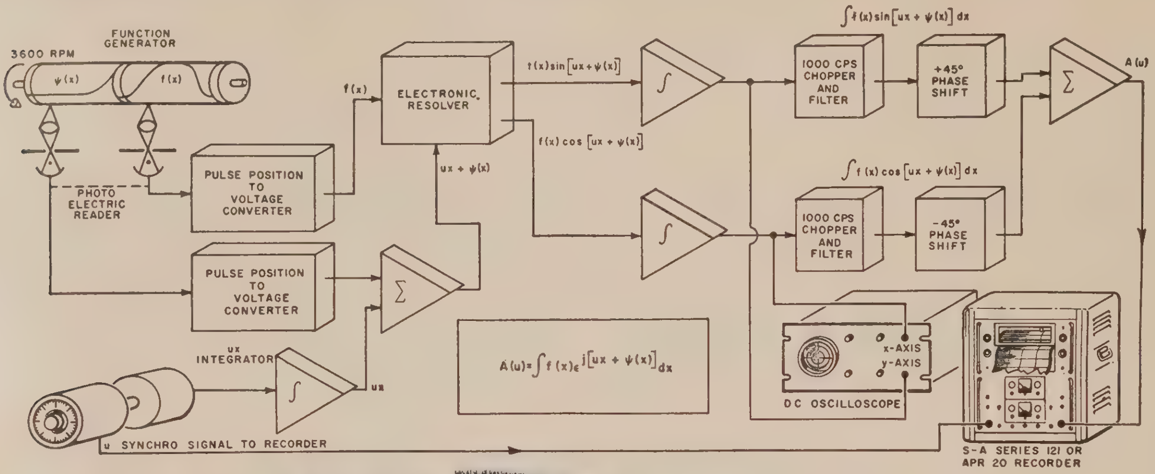
P. O. Box 508, Ottawa 4, Ontario, Canada

Simplified block diagram of Model CF-1. Amplitude and phase input functions are plotted on graph paper for presentation. Integration is observed on a dc oscilloscope. Absolute magnitude is recorded on any S-A Series 121 or APR 20 Antenna Pattern Recorder with a logarithmic response.

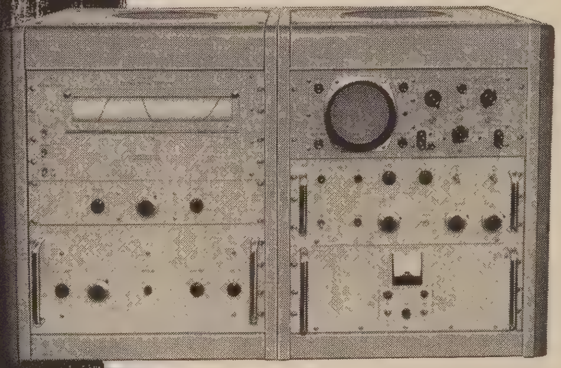

3600 RPM
FUNCTION GENERATOR
ψ(x)
f(x)
PHOTO ELECTRIC READER
PULSE POSITION TO VOLTAGE CONVERTER
PULSE POSITION TO VOLTAGE CONVERTER
f(x)
ELECTRONIC RESOLVER
ux + ψ(x)
Σ
ux INTEGRATOR
ux
u SYNCHRO SIGNAL TO RECORDER
f(x) sin [ux + ψ(x)]
f(x) cos [ux + ψ(x)]
A(u) = ∫ f(x) ϵ^j[ux + ψ(x)] dx
∫ f(x) sin [ux + ψ(x)] dx
∫ f(x) cos [ux + ψ(x)] dx
1000 CPS CHOPPER AND FILTER
1000 CPS CHOPPER AND FILTER
+45° PHASE SHIFT
-45° PHASE SHIFT
Σ
A(u)
x-AXIS
y-AXIS
DC OSCILLOSCOPE
S-A SERIES 121 OR APR 20 RECORDER

To solve

$$A(u)=\int_{-1}^{1} f(x)\,\epsilon^{\,j[ux+\psi(x)]}\,dx$$

investigate the new

FOURIER INTEGRAL COMPUTER



Model CF-1

A sophisticated solution to the vexing problem of solving bounded Fourier integrals quickly and accurately, Scientific-Atlanta designed the Model CF-1 especially for the antenna design engineer.

The computer has broad general application including determination of the far fields of aperture antennas from the distribution of the field in the aperture, the far fields of arrays from the magnitude and phase of the currents in the elements, the frequency spectra of voltage pulses, and other physical problems involving Fourier transforms and their inverse transforms over finite limits.

PRICES

Model CF-1 Fourier Integral Computer . . . $9,000

Model APR 22 Antenna Pattern Recorder (logarithmic response) . . . $4,300

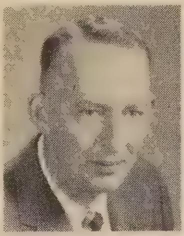
Consult your nearby S-A engineering representative for more information. Or you may write directly to the factory for complete specifications. Address Dept. 86.

SCIENTIFIC-ATLANTA, INC.
2162 PIEDMONT ROAD, N.E. • ATLANTA 9, GEORGIA
Tel. TRinity 5-7291

4

(Continued from page 80A)

Company, Inc., Santa Fe Springs, Calif.



E. H. LOCKHART

A veteran of over 20 years with the electronics industry, he most recently was vice-president of Radiatronics Incorporated, Van Nuys, Calif. He has also had engineering and management experience with Hughes Aircraft Company, Stanford University Microwave Laboratory, Los Alamos Scientific Laboratory, University of California Radiation Laboratory, and General Electric Company.

He has been active in the Western Electronic Manufacturer's Association for many years, serving on the Membership Committee in 1955, Greeters Committee Chairman 1956, Program Chairman 1957, and as a Director in 1958 and 1959.

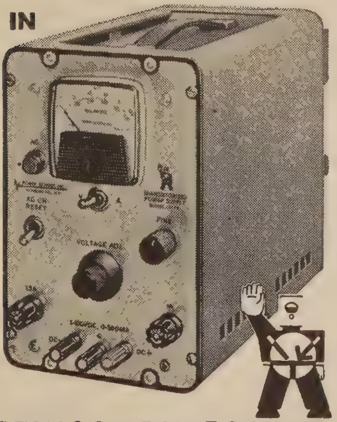
Mr. Lockhart served as Registration Chairman for the 1958 Wescon, and is Vice-Chairman of the All Industry Luncheon Committee for the 1960 Wescon. His affiliations include the Aircraft Electrical Society and AFCEA.

❖

(Continued on page 198A)

ROBOTEC®

IN

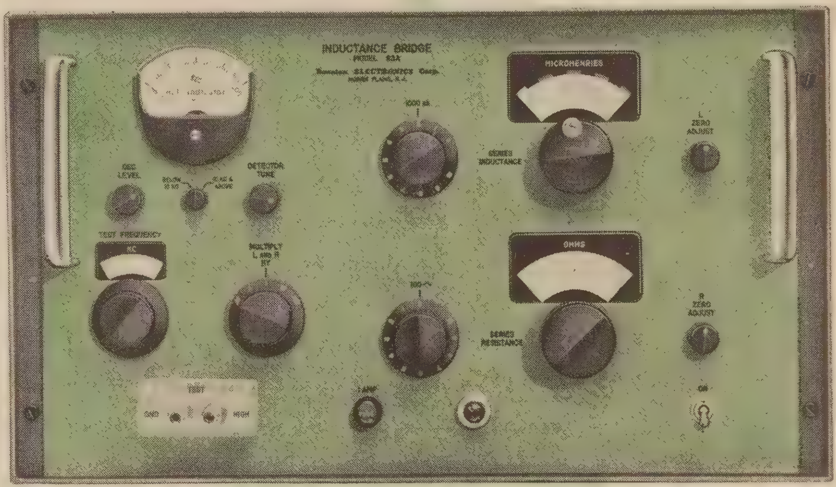

VOLTAGE ADJ.

SEMICONDUCTORIZED
VOLTAGE REGULATED
POWER SUPPLIES

. . . electronically cuts off output in less than 30 microseconds with overload or short circuit. Permits safe continuous operation into dead short. Models up to 100 volts and 10 amperes. Write for literature RI.

Power Designs inc.
1700 SHAMES DRIVE
WESTBURY, NEW YORK
EDgewood 3-6200

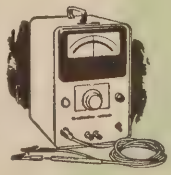
Wide-Range
Self-Contained
Precision
Inductance Bridge


INDUCTANCE BRIDGE
MODEL 63A
Boonton ELECTRONICS Corp.
MICROHENRIES
SERIES INDUCTANCE
L ZERO ADJUST
OSC LEVEL
DETECTOR TUNE
TEST FREQUENCY
KC
MULTIPLY L AND R BY
OHMS
SERIES RESISTANCE
R ZERO ADJUST
LAMP
ON
TEST
GND
HIGH

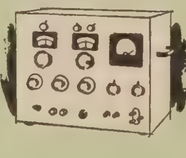
MODEL 63A PRICE $1500

- Inductance Range: .002 Microhenry to 1.1 Henries.
- Series Resistance Range: .002 Ohm to 110K Ohms.
- Built-in 1 to 100 KC Oscillator – Detector.
- No False or Sliding Nulls.

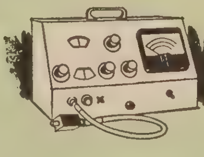
ALSO MANUFACTURERS OF THESE FINE INSTRUMENTS



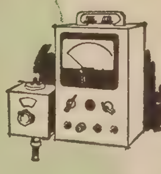
DC Millivoltmeter



Capacitance Bridge



RF Distortion Meter

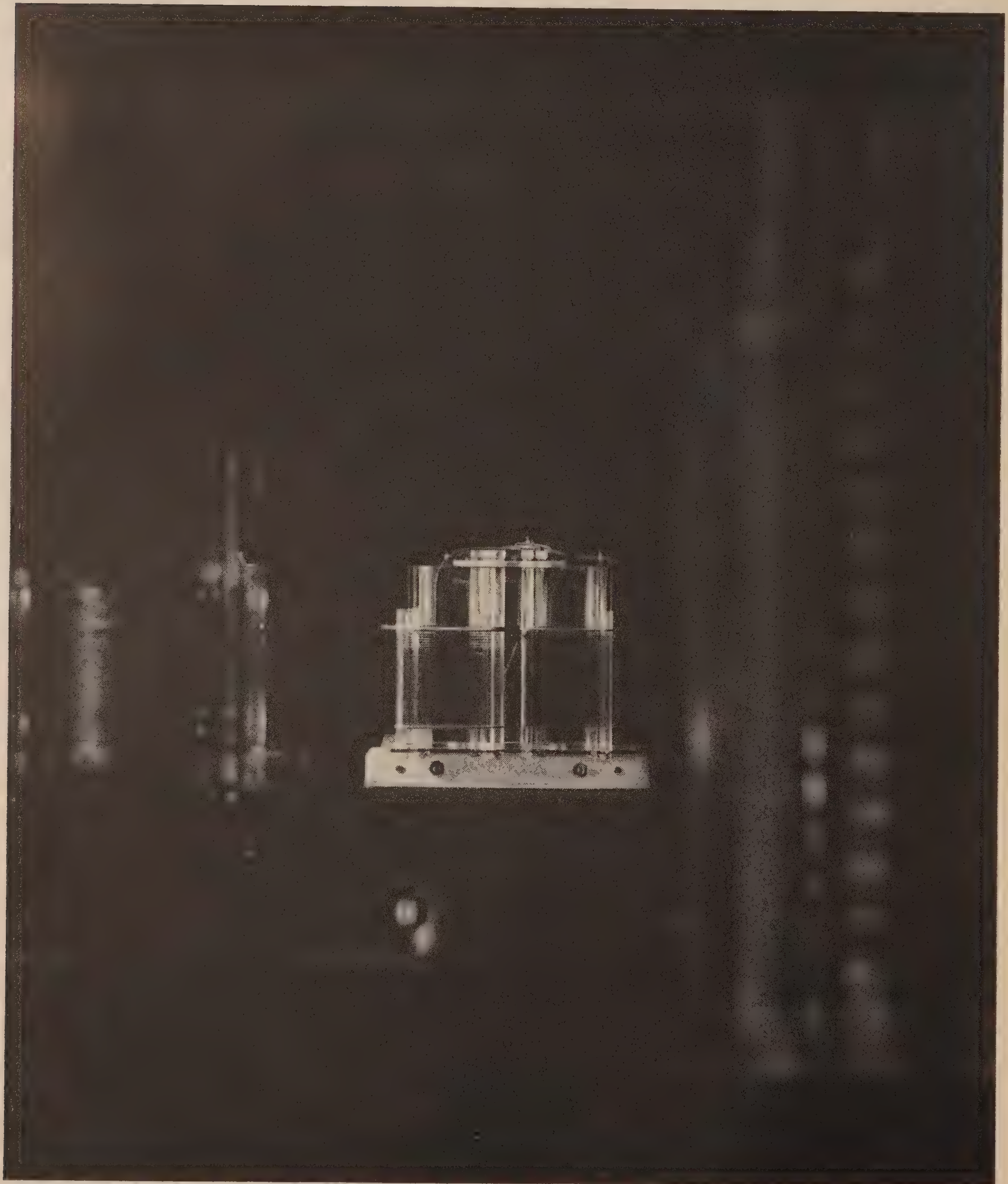


UHF Grid Dip Meter

Boonton ELECTRONICS Corp.
Morris Plains, New Jersey • Phone: JEfferson 9-4210

A pulse transformer. Wire wound in careful coils. Metals, magnetic materials and dielectrics combined in careful ratios, spacings and dimensions. The result: a device with precise parameters—pulse shape, rise/fall times, ripple, backswing, overshoot, life. What sets this one apart? A unique thing—Carad capability. Capability gained in designing and building hundreds of special pulse transformer types to exact specifications. Weights from ounces to hundreds of pounds. Ratings from 10 volts to 500 kv. None of these extremes are considered limits at Carad. For pulse transformers of any type you will find it worth your while to investigate Carad capability.

CARAD CORPORATION 2850 Bay Road • Redwood City • California



FROM **Transitron**...INDUSTRY'S BROADEST LINE OF

MICRO-DIODES

MICRO-MINIATURIZATION POSSIBLE NOW!

YES — FASTEST DIFFUSED SILICON MICRO-DIODES AVAILABLE. They combine advanced diffusion techniques with extremely small size, to provide milli-micro-second switching speeds, excellent static, forward and inverse characteristics.

YES — ONLY SERIES OF HIGH QUALITY MICRO-REGULATORS. Series of 8 diffused-silicon micro-regulators provides stable voltage regulation and reference sources previously found only in considerably larger devices. Excellent dynamic resistance characteristics.

YES — BASIC FAMILY OF MULTI-PURPOSE MICRO-DIODES. Series of 3 high quality diffused-silicon micro-diodes provides voltage ratings up to 200 volts, current rating up to 50 milliamperes. May be considered for switching applications. Exceptional static, forward and inverse characteristics.

YES — EVEN A MICRO-STABISTOR.
This diffused-silicon stabistor is the micro-counterpart of Transitron's universally-known SG-22.

All of these new micro-diodes are COMPLETELY COMPATIBLE with present circuitry . . . provide the same excellent performance as larger Transitron diodes in 1/10th the space! Here is your chance to micro-miniaturize circuits TODAY!

VERY FAST SWITCHING MICRO-DIODE

TYPE	PIV	E_f @ 5 MA	RECOVERY TIME
TMD-50	50V	0.75V	4 mμsec

FAST SWITCHING MICRO-DIODE

TYPE	PIV	E_f @ 20 MA	RECOVERY TIME
TMD-24	50V	0.85V	0.3 μsec
TMD-25	100V	0.85V	0.3 μsec
TMD-27	200V	0.85V	0.3 μsec

SILICON MICRO-REGULATOR

TYPE	VOLTAGE @ 5 MA	POWER RATING @ 25°C
TMD-01	5.1V	100 MW
TMD-03	6.2V	100 MW
TMD-07	9.1V	100 MW

HIGH CONDUCTANCE MICRO-DIODE

TYPE	PIV	E_f @ 100 MA	POWER RATING @ 25°C
TMD-41	50V	1.0V	100 MW
TMD-42	100V	1.0V	100 MW
TMD-45	200V	1.0V	100 MW

SILICON MICRO-STABISTOR

TYPE	E_f @ 1 MA	DYNAMIC RESISTANCE
TMD-40	0.55V	60 OHMS

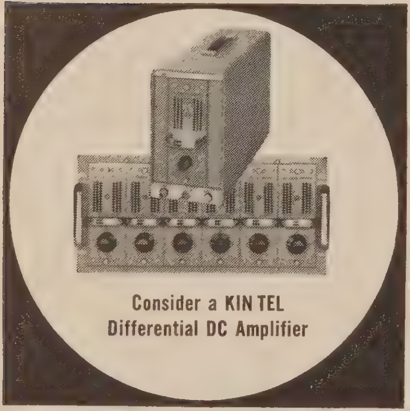
For further information, write for Bulletins:
PB-71A (High Conductance), PB-71B (Fast Switching), PB-71C (Very Fast Switching), PB-71D (Stabistor), PB-71E (Regulators); AN 1358A Application Notes.

See Transitron at the AFCEA Show, Booths 157-158

Transitron
electronic corporation • wakefield, massachusetts
"Leadership in Semiconductors" SEE YOUR LOCAL AUTHORIZED TRANSITRON DISTRIBUTOR FOR QUANTITIES FROM 1-999.

if

you want to make 0.1% strain, temperature, and other measurements ...rescue microvolt signals from volts of noise...



Consider a KIN TEL Differential DC Amplifier

The KIN TEL 114A virtually eliminates ground loop problems...amplifies microvolt level signals in the presence of volts of common-mode noise. Input is isolated from output and both are completely isolated from chassis ground. Common-mode rejection is 180 db for DC, 130 db for 60 cps with up to 1000 ohms input unbalance. Equivalent input drift $<3\,\mu$v, input resistance 5 megohms, output capability 10 volts at 10 ma, gain 10 to 1000, bandwidth 100 cps, gain stability 0.1%. There's no better way to measure strain, temperature and other phenomena to very high accuracies. Price: 114A $875, single amplifier cabinet $125, six amplifier module $295.

Representatives in all major cities

KIN TEL
A DIVISION OF
COHU
ELECTRONICS, INC.

5725 Kearny Villa Road, San Diego 11, California
Phone: BRowning 7-6700

Industrial Engineering Notes*

AIR TRAFFIC CONTROL

The Federal Aviation Agency hopes to have air traffic control on a semi-automatic basis by 1963 and fully automatic "as soon as possible thereafter," FAA Administrator E. R. Quesada said .Speaking at a meeting of the National Society of Professional Engineers, Mr. Quesada said a 400-engineer staff is working on R&D connected with modernization of the airways and that one of the most pressing projects is the automation of the air traffic control system. Automation has, he said, "terrifically far-reaching implications. The key to the project is the development of an air traffic control Data Processing Central that will remove many of the controller's bookkeeping chores and give him more time to analyze traffic situations and make control decisions." The Central's "most spectacular" function will be in probing, detecting, and predicting conflicts, he continued. It will warn of any unsafe situation and automatically suggest corrective alternatives. Present plans call for the Central to be controlling the New York, N. Y., area's air traffic in 1963, with systems to follow at Cleveland, Washington, Chicago, Los Angeles, and Oakland. Other plans for airway modernization call for increased installations of radar and other electronic equipment; improving the communications systems and the aeronautical weather service; and developing new control procedures, the administrator said.

ENGINEERING

Standards on resistors and capacitors have just been published by the American Standards Association. Publication 115 applies to fixed resistors of types other than wire-wound, with a rate dissipation not exceeding 2 watts and a rated resistance value between 10 ohms and 10 megohms, suitable for use in circuits where high stability properties are essential. Publication 116 applies to fixed capacitors with a dielectric of mica with the electrodes directly deposited on the mica sheets and intended for use in telecommunication receiving equipment and for similar applications in other electronic equipment. Copies of these publications are available from ASA Headquarters 70 E. 45th St. New York, N. Y., $3.20 per copy. . . . **A two-part report of Air Force-sponsored research into magnetic amplifier circuits has been published for sale to industry through the Office of Technical Services, U. S. Department of Commerce, Washington 25, D. C.**

MILITARY ELECTRONICS

The Army has shown members of the press a device which can, it was claimed, perform many of the functions of electronic devices—without electricity or moving parts. The device is a "pure fluid amplifier." The unit demonstrated by its inventors, scientists of the Army's Diamond Ordnance Fuze Laboratory in Washington, resembled a block somewhat larger than a pack of playing cards. It was airtight, except for tiny apertures, and contained passageways. Attached to a source of pressurized gas or liquid, the device can amplify, digitalize, remember, feedback, and compute, the scientists said. The new device "makes possible a whole new class of amplifiers, computers, logic circuits and control systems, and will bring automation and control more into industrial and personal life," its developers said. The "revolutionary" system will not replace the electronics industry, they declared, but in some specialized applications it "will do things better and more reliably than electronic systems." "Pure fluid amplifying and computing elements will take a place in hydraulic and pneumatic systems similar to the position that the vacuum tube and transistor occupy in the field of electricity," the scientists said. The amplifier works by injection into the internal passageways of one strong stream of gas or liquid and a second, weaker stream which displaces or redirects the main flow. The idea for the system is an old one—"an overlooked one," its developers said. Fluids in motion have been used in many applications, such as hydraulic systems, windshield wipers and autopilots. But those systems have moving parts. The advantage of the pure penumatic device is that it has none. Thus, the inventors claimed, it is trouble-free to an astonishing degree, easy to make and maintain, and as rugged as its few component materials are. It can operate, for example, in white heat. The inventors said a unit could be produced for 2/10ths of a cent which would do the work of a vacuum tube costing 50 cents. A unit the size of a pea with an aperture 5/1000ths of an inch in diameter was displayed. It was said that the size of the device could be adjusted to fit almost any applications "up into the horsepower range." The prime advantage is the speed of the device. "They will never compete with electronic systems for very high speed applications," the scientists said. The pure fluid amplifier will be described in an engineering handbook now being prepared by the Army and in a series of technical papers to appear in trade magazines. A full technical report will be issued later.

(Continued on page 92A)

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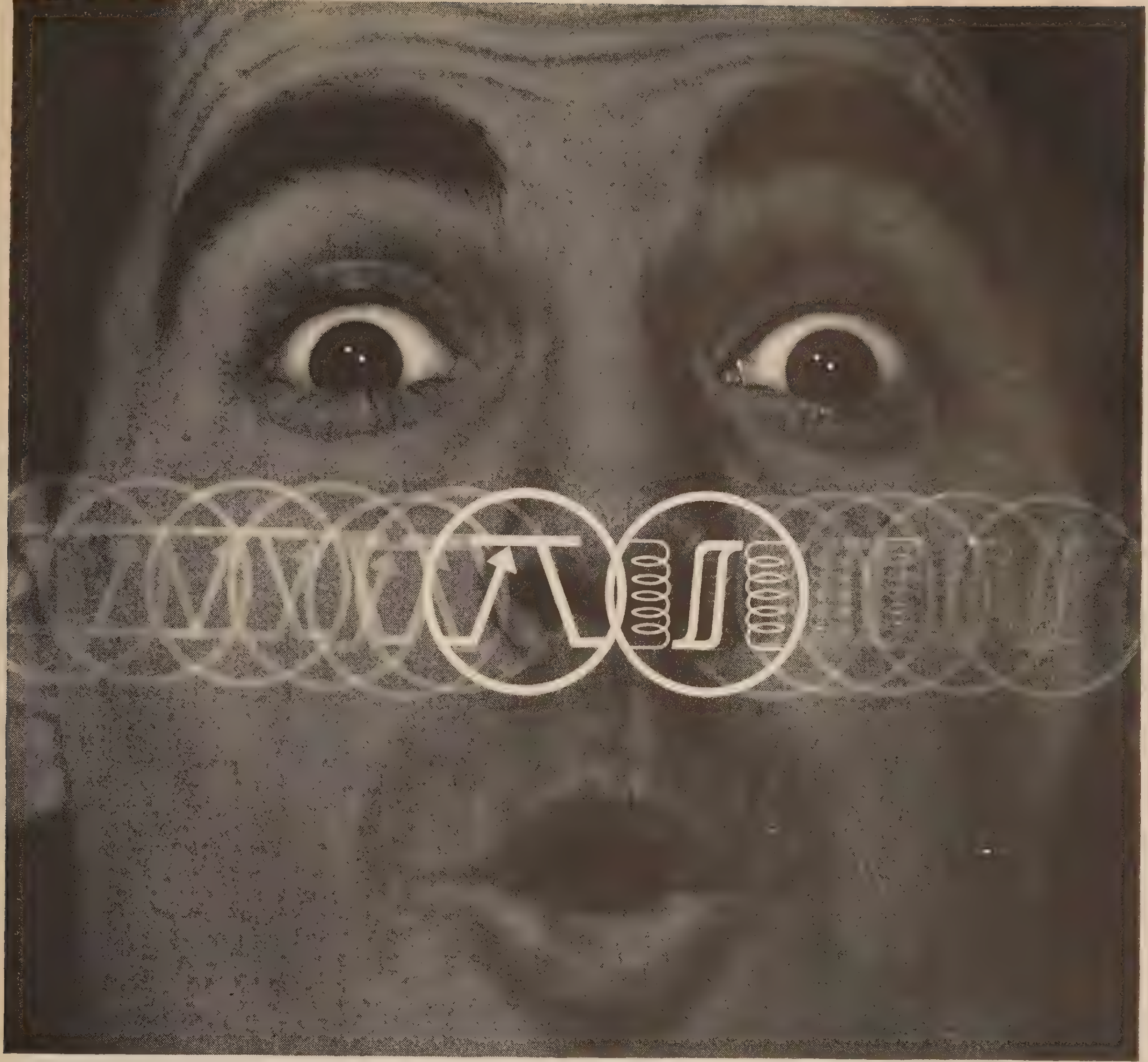
* The data on which these NOTES are based were selected by permission from *Weekly Report* issues of February 23 and March 7, 1960, published by the Electronic Industries Association, whose helpfulness is gratefully acknowledged.

PUTTING MAGNETICS TO WORK



Open your eyes to new amplifier designs!

See how to combine tape wound cores and transistors for more versatile, lower-cost, smaller amplifiers

Tie tape wound cores and transistors into a magnetic-transistor amplifier, and open your eyes to new design opportunities.

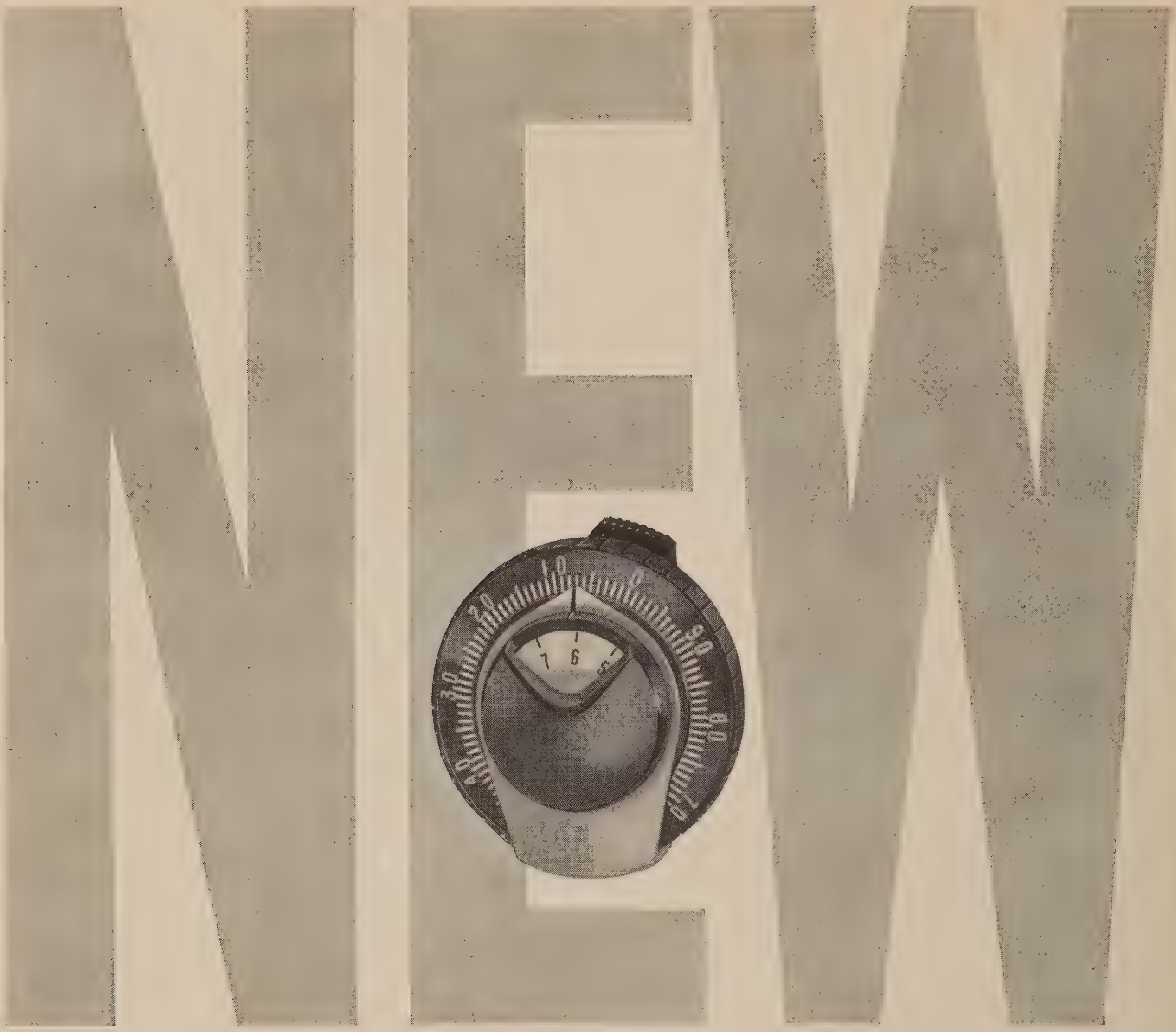
To start with, these are static control elements—no moving parts, nothing to wear or burn out. Next thing you find is that you reduce components' size—your amplifier is smaller and costs less. That's because between them the core and the transistor perform just about every circuit function . . . and then some.

For instance? The core has multiple isolated windings. Thus you can feed many inputs to control the amplifier. The core also has a square hysteresis loop, and thus acts as a low loss transformer. That means you save power. In addition, the core can store and remember signals—so time delay becomes simple.

There's no need for temperature stabilization, either. The transistor acts only as a low loss, fast, static switch—and in this function it has no peer.

How do you want to use this superb combination? As a switching amplifier—or a linear one? In an oscillator? A power converter (d-c to d-c or d-c to a-c)? You'll have ideas of your own—and if they involve tape wound cores, why not write us? Ours are Performance-Guaranteed. *Magnetics Inc., Dept. P-81, Butler, Pennsylvania.*

MAGNETICS inc. ®



NEW BORG MICRODIALS ADD RICHNESS AND STYLE TO CONTROL PANELS AND INSTRUMENTS

Now from Borg, originator of famous Microdials, comes a fresh, new concept in turn-counting dial appearance . . . Series 1360 Microdials. These new Borg Microdials were specially developed to add style and color to electronic control panels and equipment. Available in five smart models of red, gray and black color variations. Colors are inlays of colored plastic . . . will never wear, scale or rub off. Quality mechanical features such as smoothness of action . . . absence of noise . . . fewer ambiguities in reading and setting assure accurate, reliable performance. Contoured brake arms lock settings in place, but do not interfere with reading and setting. Catalog data sheet BED-A137 gives complete color combinations and specifications. See your Borg technical representative or distributor, or let us put him in touch with you.

BORG®

BORG EQUIPMENT DIVISION

Amphenol-Borg Electronics Corporation
Janesville, Wisconsin

Micropot Potentiometers • Turns-Counting Microdials • Sub-Fractional Horsepower Motors • Frequency and Time Standards

OHMITE
RESISTORS

THE EXACT RESISTOR YOU NEED—WHEN YOU NEED IT—FOR EVERY INDUSTRIAL AND MILITARY REQUIREMENT

Fixed . . . adjustable . . . tapped . . . noninductive . . . precision metal film and encapsulated wire-wound . . . thin type . . . high-current—practically any resistor you need, you can find in the Ohmite line.

WORLD'S LARGEST STOCK FOR IMMEDIATE DELIVERY—Chances are Ohmite's huge stock of several million resistors in more than 2000 sizes and types contains a unit that fits your requirements. Many types are also available through Electronic Parts Distributors located across the Nation.

YOUR CUSTOMERS KNOW THE VALUE OF OHMITE QUALITY—When a purchaser sees Ohmite resistors in a piece of equipment, he knows that equipment is designed and built for dependability.

OHMITE ENGINEERING ASSISTANCE ASSURES THE RIGHT UNIT—Selecting the right resistor for the job is sometimes a tough problem. Why not call on Ohmite application engineers to help out. Take advantage of their specialized skills and background.

Write on Company Letterhead for Catalog and Engineering Manual 58

CORRIB
POWR-RIB
ENCAPSULATED PRECISION
BROWN DEVILS
DIVIDOHM ADJUSTABLE RESISTORS
THIN RESISTORS
AXIAL LEAD
FIXED RESISTORS
ENCAPSULATED PRECISION
METAL FILM PRECISION
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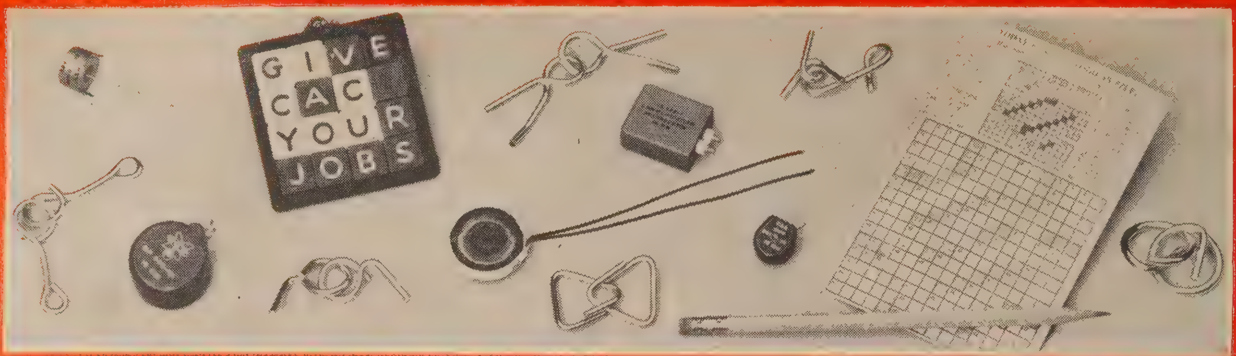
OHMITE

Quality Components

RHEOSTATS • RESISTORS • TAP SWITCHES
RELAYS • R.F. CHOKES • TANTALUM CAPACITORS
VARIABLE TRANSFORMERS • GERMANIUM DIODES

OHMITE MANUFACTURING COMPANY
3617 Howard Street, Skokie, Illinois



TOROIDS PUZZLING YOU?

NETWORKS
MAG AMPS
DELAY LINES
SATURABLE REACTORS

Advanced engineering, complete industry liaison and exclusive specialization in toroidal components are all part of a continuing program at C-A-C. Our unique equipment—designed and built by C-A-C—enables us to produce quality toroids of all types in high volume for fast delivery.

Always Specify C-A-C Toroids

C-A-C

COMMUNICATION ACCESSORIES COMPANY *Lee's Summit, Missouri*

309

50% SAVINGS with BEAD CHAIN® Multi-Swage Parts

also PRINTED CIRCUIT MINIATURE PARTS

Contact pins, terminals, jacks or any small tubular parts. Maximum ¼" diameter x 1¼" length.
Send sketch for quotations.

CONTACT PINS

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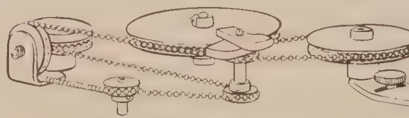
BEAD CHAIN DRIVES

Low-speed positive drives or motion transfer . . . at far less cost!



Send for Multi-Swage or Bead Chain Drive Catalogs!

QUALIFIED BEAD CHAIN

No. 3—3/32" Dia.

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No. 13—¼" Dia.

THE BEAD CHAIN MFG. CO.

Industrial Engineering Notes

(*Continued from page 88A*)

EIA PROPOSAL

EIA has submitted to the Labor Department its proposed definition of the Electronic Equipment Industry and urged that it be used in the upcoming survey preliminary to a Walsh-Healey wage determination for the industry. The EIA proposal defines the industry in terms of classes of products it manufactures, and limits the categories to those that are specifically electronic. It is intended to replace a more general definition proposed earlier by the Labor Department which identifies the industry as devoted to ". . . the manufacture of electrical apparatus and sub-assemblies therefor involving the use of electronic tubes and/or solid state semiconductor devices." In a statement accompanying its definition, EIA pointed out that the proposal would eliminate the possibility of including products of other electronic industries already covered by Walsh-Healey wage determinations, such as the electronic components and the tube and semiconductor industries. The definition proposed by EIA is "The manufacture of electronic equipment for the purpose of this survey, is defined as that industry which manufactures any of the following classes of

(*Continued on page 108A*)

An achievement in
defense electronics

NEW THERMOPLASTIC RECORDING DISPLAY ACHIEVES

Detection to Projection in Less than a Second

Large-screen display of radar signals can be recorded and projected in less than a second. This advanced technique in information display is an example of one application of the new thermoplastic recording system developed by General Electric.

The grainless, thermoplastic film eliminates processing delays and permits, with higher resolution, much greater enlargement than is practical with high-speed photographic film. Target delineation is also significantly improved by optical filtering used to increase the signal-to-noise ratio.

Now undergoing final development in General Electric's Electronics Laboratory, the "thermoplastic display" is expected to find maximum application in the high-speed radar systems of the future. 176-03

Progress Is Our Most Important Product

GENERAL ELECTRIC

DEFENSE ELECTRONICS DIVISION
HEAVY MILITARY ELECTRONICS DEPARTMENT
SYRACUSE, NEW YORK

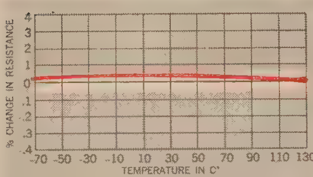
Time-tested!

— the time-tested standard of the resistor industry

Evanohm*

RESISTANCE ALLOY

— for resistors and precision instruments



Percent change in resistance of an ideal sample of Evanohm. Normal production material (.002" and finer) is supplied within the range ±10 ppm (−65° to 25°C. and 25° to 125°C, referred to 25°C.)

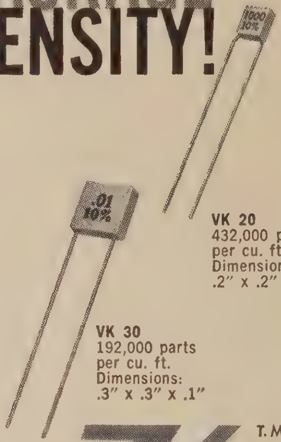
Wherever exceptional stability over a wide temperature range is essential, EVANOHM is the accepted standard of performance. This high-reliability resistance alloy provides high specific resistance, low temperature coefficient, low thermal EMF to copper. EVANOHM is especially recommended for use in resistors, aircraft instruments, for guided missiles, rockets and other precision equipment. Available in bare wire, enamel, formvar, polyurethane, silk, cotton, nylon and glass insulation. Write for complete electrical and mechanical data and recommendations on your specific application.

**Patents 2,293,878–2,638,425 — Tradename Registered*

WILBUR B. DRIVER CO.
Main Office: NEWARK, N. J.—Tel. HUmboldt 2-5550

Branch Offices and Warehouses in Principal Cities. Manufacturing Plants: 1875 McCarter H'way, Newark 4, N. J.; 2734 Industrial Way, Santa Maria, Calif. Canadian Wilbur B. Driver Co., Ltd., Rexdale (Toronto). Subsidiary: Western Gold and Platinum Co., 525 Harbor Blvd., Belmont, Calif.

HIGH PACKAGE DENSITY!



VK 20
432,000 parts per cu. ft.
Dimensions:
.2" x .2" x .1"

VK 30
192,000 parts per cu. ft.
Dimensions:
.3" x .3" x .1"

T.M.

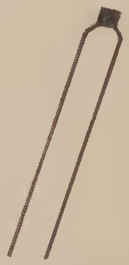
micro-miniature

CERAMIC CAPACITORS

- Decimal dimensioned case
- Max. volumetric efficiency
- Contiguous flush-mount
- 47-10,000 mmf
- 200 vdc without derating
- −55°C to 150°C operation

"VK" capacitors are designed with square precision molded cases in only two sizes and a single standard 0.2" lead spacing for all values. Continuous life and environmental testing, plus 100% tests for Dissipation Factor, Insulation Resistance, and Capacitance guarantee that each "VK" capacitor in your circuit will perform as predicted.

ALSO UNCASED
FOR COMPLETE
ASSEMBLY
ENCAPSULATION



Same electrical characteristics as standard "VK" series. Each unit coated with a resilient protective compound. Dimensions: 47-100 mmf, .100" square; 120-270 mmf, .130" square; 330-1000 mmf, .150" square; 1200-3300 mmf, .250" square; 3900-10,000 mmf, .265" square.

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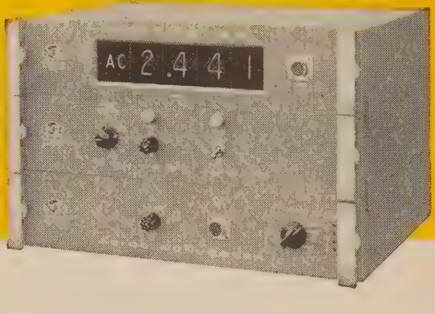
SIDE BY SIDE WITH ANY INSTRUMENTATION...



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An uncluttered, human-engineered front panel and internal engineering and construction demonstrate to the eye that Cubic's is the *superior* digital instrument. Proof of this superiority is in the *operation* . . . and side by side in independent evaluations of many instruments, Cubic again and again provides the instrumentation that is *specified*.

Any phenomenon of science which can be converted to a usable DC Voltage can be measured with the Cubic 4 or 5-digit Voltmeter (Models V-41, V-51) powered by the Model C-1 Control Unit. Addition of an AC Converter (Model AC-1, manual ranging; Model AC-2, automatic ranging) or a Model PA-1 Preamplifier extends the systems capabilities to the measurements of AC voltages or lower level DC voltages.

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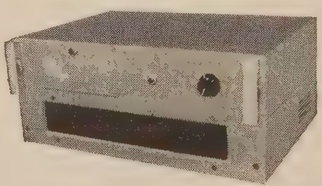
Multiple input channels may be sampled rapidly and accurately with the Model MS-2, a single unit for scanning up to 100 points, or the MS-1, AS-1 Master-Auxiliary combination for scanning up to 1000 points with multiples of one, two, four or five-wire inputs.

Voltage ratio measurements are made with the R-41 and R-51 4 and 5-digit models operating only as Ratiometers or with the VR-41 and VR-51 models, which operate both as Ratiometers and Voltmeters. Measurements can be permanently recorded with the addition of a PC-Series Printer Control Unit, providing input for any quality printer on the market.

AND NEW FROM CUBIC . . . the Talking Meter, instrumentation that really *does* speak for itself, instrumentation that provides a new dimension in "readout," measurements or other parameters reported to the ear by a clear human voice.



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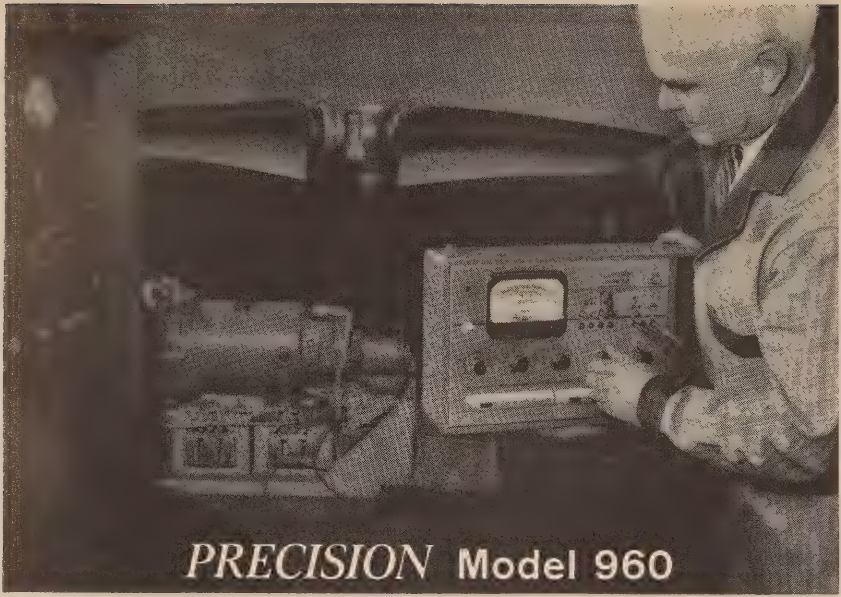

PRECISION Model 960

transistor and crystal diode tester . . .

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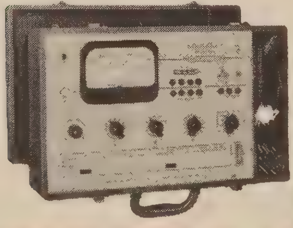
THE PROBLEM:

Curtiss-Wright needed an accurate and reliable transistor tester, for field testing and maintenance of their transistorized Propeller Synchronizer and its associated equipment.

THE SOLUTION:

After evaluating available test instruments, the ***PRECISION*** Model 960* was chosen on the basis of its design suitability, reliability and low unit cost.



*The Model 960 is a comprehensive test set designed for economical, practical and reliable checking of transistors and crystal diodes • specialized circuitry and operating parameters have been engineered in cooperation with leading semiconductor manufacturers • self contained AC power supply eliminates the necessity for batteries • $99.95

Perhaps you, too, have a production-line or servicing problem that can be solved by the ***PRECISION*** Model 960 . . .

If so, you will be interested to learn that the Model 960, and all other ***PRECISION*** test instruments, are available to you now for a free trial . . . in your plant . . . under actual operating conditions . . . without obligation.

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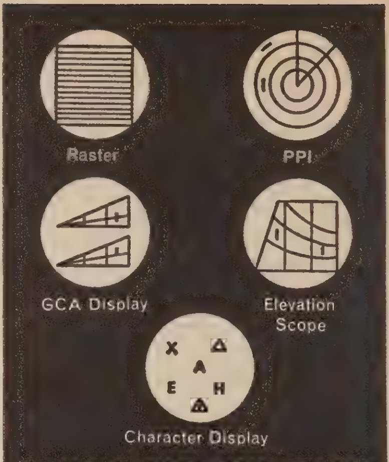
Export: 458 Broadway, New York 13, New York
Canada: Atlas Radio Corp., Ltd., 50 Wingold Ave., Toronto 19



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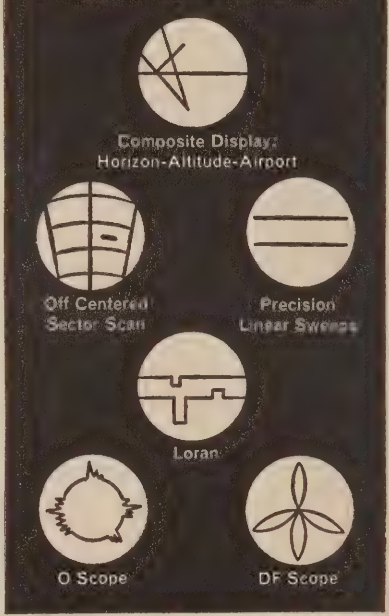

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WHAT HAS THE **7182 S BAND MAGNETRON** IN COMMON WITH THIS CAT?

*

A good question! According to legend, a cat has nine lives—something that has yet to be proved. The 7182, on the other hand, has a *proved* life 8 to 10 times greater than any similar S-Band magnetron.

The 7182 retains its remarkable stability and reliability during a life of 10,000 hours, and is one of a series of magnetrons now in production providing peak powers of 5 MW. These magnetrons operate at voltages and current densities usually associated with magnetrons rated at a fraction of the power output.

A parallel development in L-Band ensures that attainments in this field equal the phenomenal successes already achieved with S-Band magnetrons.

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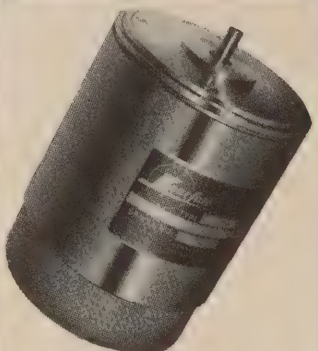
AP 134

BASIC BUILDING BLOCKS FROM KEARFOTT



20 SECOND SYNCHRO

This synchro, just one of a broad line offered by Kearfott, provides the extreme accuracy required in today's data transmission systems. Kearfott synchro resolvers enable system designers to achieve unusual accuracy without the need for 2-speed servos and elaborate electronics. By proper impedance, matches up to 64 resolver control transformers can also operate from one resolver transmitter.

TYPICAL CHARACTERISTICS

	SIZE 25	
Type Resolver	Transmitter	Control Transformer
Part Number	Z5161-001	Z5151-003
Excit. Volts (Max.)	115	90
Frequency (cps)	400	400
Primary Imped.	400/80°	8500/80°
Secondary Imped.	260/80°	14000/80°
Transform. Ratio	.7826	1.278
Max. Error fr. E.Z.	20 seconds	20 seconds
Primary	Rotor	Stator

Write for complete data.

BASIC BUILDING BLOCKS FROM KEARFOTT

PRECISE ANGLE INDICATOR

Consisting of an angle position indicator, motor and servo amplifier, this small, versatile, rack panel mounted unit provides angular position indications for laboratory, production and field use. Input signals proportional to unknown angular position of synchro device being measured are resolved as an error voltage, which is amplified and used to drive an internal servo loop to null. Counter mechanism then provides direct visual readout of angular position.

TYPICAL CHARACTERISTICS

Input Signal: S_1, S_2, and S_3 of external synchro transmitter.

Repeatability: Within 0.6 minute in either a clockwise or counterclockwise direction for any angular position.

Readability: 0.5 minute through full range from zero to 360° Rotation is continuous.

Accuracy: ± 6 minutes in the standard unit. Other accuracies available on request.

Sensitivity: 0.5 minutes maximum.

Slewing Speed: Phase sensitive, 180° in 7 seconds.

Input Voltages: 115 volts, single phase, 400 cycles, 23 VA max.

Size: Standard Rack Mounting—1¾" x 9½" x 8½"

Write for complete data.

BASIC BUILDING BLOCKS FROM KEARFOTT

FLOATED RATE INTEGRATING GYROS

Specifically designed for missile applications, these Kearfott miniature gyros operate efficiently at unlimited altitudes. Their outstanding accuracy and performance make them superior to any comparably-sized units on the market. Hermetically sealed within a thermal jacket, these gyros are ruggedly designed and completely adaptable to production methods. Performance characteristics that are even more precise can be provided within the same dimensions.

TYPICAL CHARACTERISTICS

Mass Unbalance:
  Along Input Axis: 1.0°/hr maximum untrimmed

Standard Deviation (short term):
  Azimuth Position: 0.05°/hr
  Vertical Position: 0.03°/hr

Drift Rate Due to Anisoelasticity
  Steady Acceleration: .015°/hr./g^2 maximum

Vibratory Acceleration: .008°/hr./g^2 maximum

Damping:
  Ratio of input angle to output angle is 0.2

Characteristic Time: .0035 seconds or less

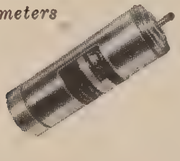
Weight: 0.7 lbs.

Warm-Up Time: 10 minutes from −60°F

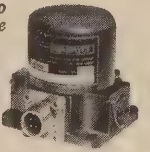
Life: 1000 hours minimum

Write for complete data.

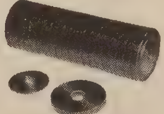
Tachometers



Servo Valve



Ferrites



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HIGHER CURRENT THAN EVER BEFORE FOR MILITARY AND COMMERCIAL USE

	2N1518	2N1519	2N1520	2N1521	2N1522	2N1523
Maximum Collector Current (Amps.)	25	25	35	35	50	50
Maximum Collector to Base Volts, Emitter Open, Max Ico 4ma	50	80	50	80	50	80
Minimum Open Base Volts (1-Amp. Sweep Method)	40	60	40	60	40	60
Maximum Saturation Volts at Maximum Collector Current	0.7	0.7	0.6	0.6	0.5	0.5
Gain at Ic at 15 Amps.	15-40	15-40	17-35	17-35	22-45	22-45
Minimum Gain at Maximum Collector Current	12	12	12	12	12	12
Thermal Resistance Junction to Mounting Base (°C/Watt)	0.8	0.8	0.8	0.8	0.8	0.8

Characteristics at 25°C Maximum Junction Temperature 95°C

A new family of high current transistors featuring the 50-ampere 2N1522 and 2N1523. Two 25- and two 35-ampere types round out the line. All thoroughly tested and completely reliable. Available in production quantities. Call or write your nearest Delco Radio sales office for full product information and applications assistance.

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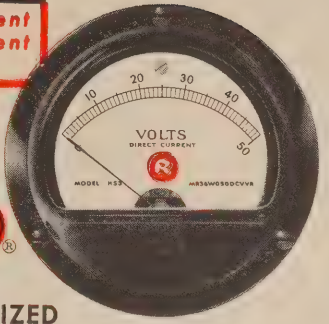
advancement in instrument design



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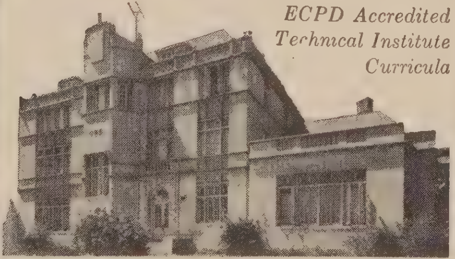

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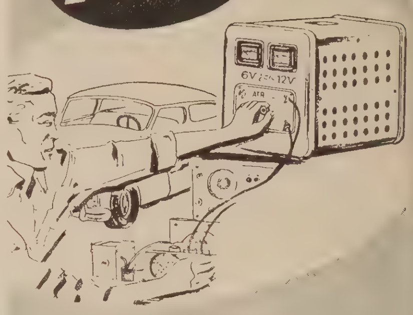
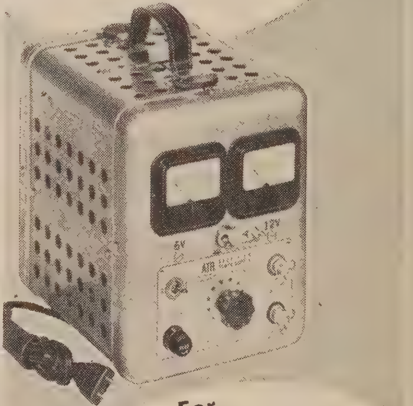


"A" BATTERY ELIMINATORS



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620C-ELIT	110	6 -or- 12	20 10	40 20	33	$66.95

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TOP LEVEL MEETING IN NATION'S CAPITAL

Washington, D.C., April 4 (AFCEA). The Armed Forces Communications and Electronics Association will hold its 14th National Convention and Exhibit in the nation's capital on May 24-26.

Because the Convention is a *common ground* meeting place, it affords you the perfect opportunity to get to know the most important members of the Services and

This bulletin is news for you if you're looking for big military contracts

The annual AFCEA National Convention and Exhibit really is a top level meeting, where you join the upper sales echelons as your own ambassador, and introduce your products in the most strategic of all areas.

Here you mingle with the cream of the electronics and communications industry, and the top representatives of the Armed Forces and government. Your firm and its products will be on display for a large, exclusive audience of market V.I.P.'s – all of whom are prospective customers.

Because the Convention is a *common ground* meeting place, it affords you the perfect opportunity to get to know the most important members of the Armed Services and your industry.

You meet with military purchasers and manufacturing colleagues; personal contact with those in the know keeps you up to date on the latest needs and projects of the military, as well as current industry research and developments.

The Exhibit is a must for manufacturers who want to sell in the most profitable of all markets. It serves as a big, bright showcase which attracts buyers from all over the country, and you as an exhibitor identify yourself in the most practical way as being a supplier in *the* market. Remember, almost all of the viewers of your display are prospective purchasers. A good, working display makes the contacts for you, and can mean on-the-spot sales!

The AFCEA Convention and Exhibit are both held in Washington's Sheraton-Park Hotel, where for three days you are kept busy and stimulated by:

> *Panel discussions* which feature carefully-prepared *professional papers* on timely military-electronics subjects, presented by well-known engineers and scientists.
>
> Interesting *speeches* on significant themes, given by famous military and industry personalities.
>
> A tour, conducted by the U.S. Army, through a large military installation.
>
> *Banquets, receptions* and *luncheons* which provide still more occasions for profitable contacts.
>
> And, of course, the 94 displays set up in the exhibition hall of the famous hotel.

"Communications and Electronics—the arm of control, the voice of command," is the theme of AFCEA's 1960 Convention and Exhibit. The Exhibit will reflect the amazing progress this young industry is making; wouldn't you like to show what your own firm has accomplished?

As a service to each exhibitor advertising in SIGNAL, the official publication of the AFCEA, a free ad in the exhibit listings of both SIGNAL and the official program is offered. Such wide advertising coverage gives added sales impact. The May issue of SIGNAL gives full coverage to the AFCEA Convention and Exhibit. In itself an "Exhibit in Print," this issue will be out in advance of the big event, spotlighting your products and serving to direct visitors to your display at the Exhibit. The issue will be indispensable as a guide to this year's Convention and Exhibit, since it will contain a complete list of exhibitors and the products to be displayed, as well as advance data about all technical papers, meetings, and other special activities.

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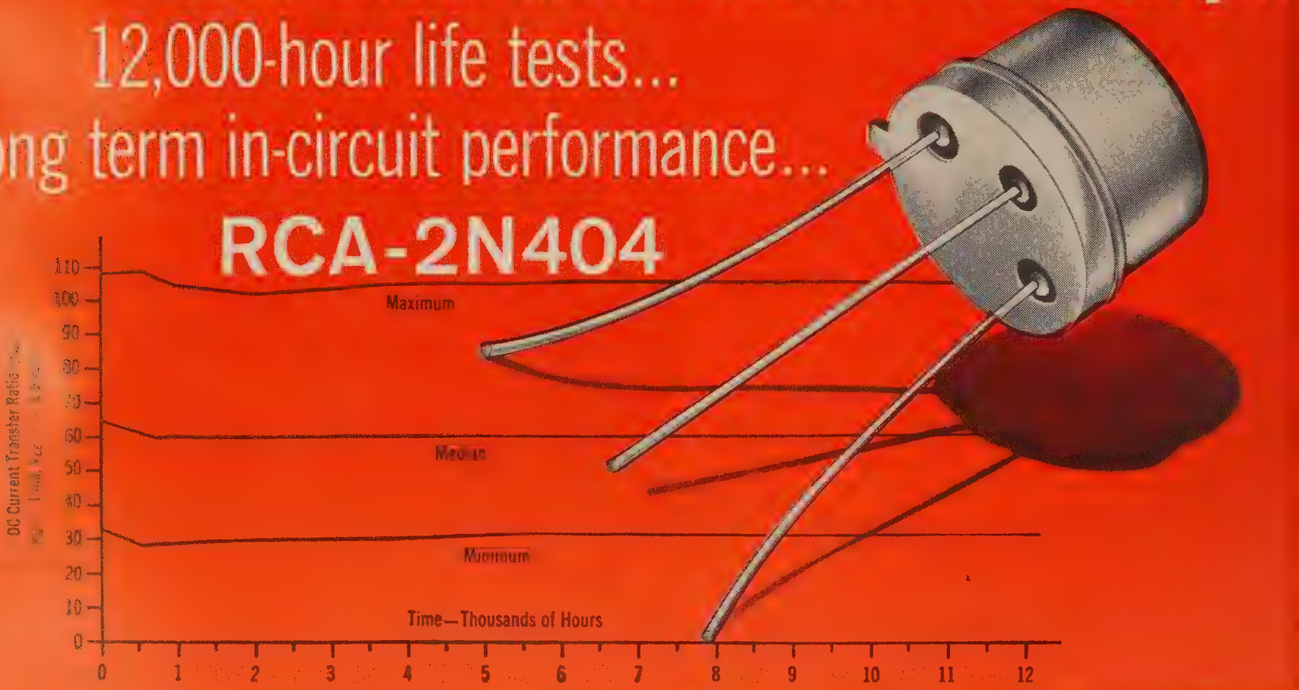


Variation in h_{FE} during a 35-mw life test at 55°C

The transistor that helped build an industry ...designed, built and introduced by RCA... chosen by top manufacturers for the finest computers...the RCA-2N404 has set new standards of reliability for transistorized computers

Outstanding new achievements of operating reliability, long life, and stability are being made by the RCA-2N404 germanium p-n-p medium-speed switching transistor. Stringent long-term life tests and dynamic in-circuit performance checks, both at maximum ratings, provide additional proof of the bedrock reliability of the RCA-2N404.

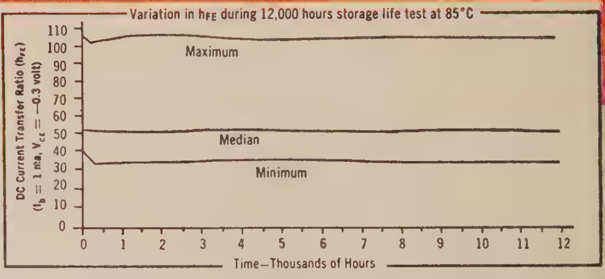
Here are the results:

(1) Representative samples of the RCA-2N404 computer transistor have now passed 12,000 hours of operating life at *maximum* ratings. The curves at the right show the remarkable stability of transistor parameters over this exceptional time period.

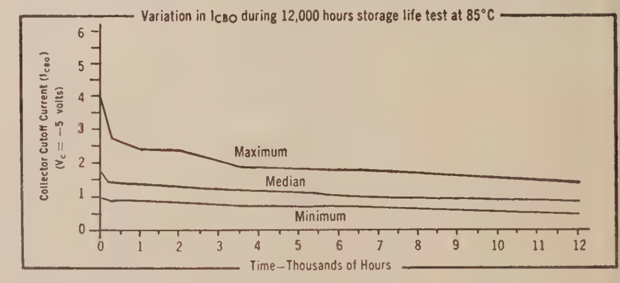
(2) Samples from every lot of RCA-2N404 transistors are tested at *maximum* ratings for 1,000 hours. During 1959, almost 6,000,000 transistor test-hours at 85°C junction temperature were logged.

Why not call your RCA Field Representative today for the full story on the RCA-2N404 and the RCA-2N404 designed to meet military specification MIL-T-19500/20 USAF. For technical information write RCA Commercial Engineering, Section E-35-NN, Somerville, N.J.

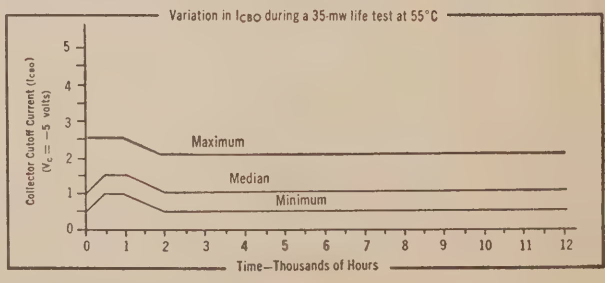
Variation in h_{FE} during 12,000 hours storage life test at 85°C



Variation in I_{CBO} during 12,000 hours storage life test at 85°C



Variation in I_{CBO} during a 35-mw life test at 55°C



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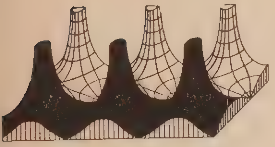
May, 1960
Vol. 48 No. 5

Proceedings of the IRE

Poles and Zeros



Section Publications. The issuance, in March, 1960, of a new edition of the "Manual for IRE Section Publications" recalls again the local Section phase of IRE "information processing." Poles and Zeros tossed a bouquet (Roses to Ye Editors) to the Section publications in April, 1959. It can now report a little over a year later, not only that old standbys are flourishing but also that two new infants are born. The new additions are the "Denshi Tokyo" and "The Benelux Bridge" of the Tokyo and Benelux Sections, respectively. We wish the newcomers well and trust that they will take their rightful place in the sun. Sections that contemplate a publication venture should acquire a copy of the Sections Publication Manual; it is filled with pertinent and helpful information.

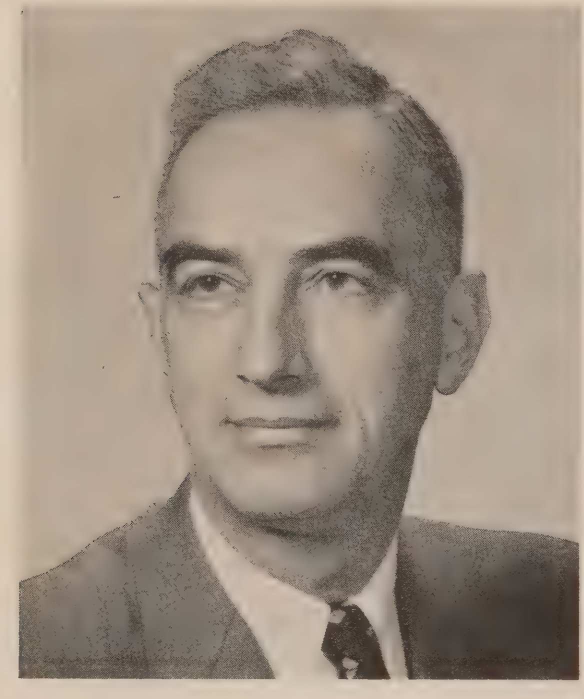
Feedback. The Editor of any publication receives mail from readers containing both constructive criticism, and destructive diatribe. Fortunately, the distribution of mail (to this Editor, so far) is weighted on the constructive side. Every etter has received, or is receiving, attention from the Editorial Board. Occasionally, the sequence of correspondence is in itself helpful. On two successive days letters were recently received. The first letter suggested that all issues of the PROCEEDINGS should be "Special Issues" and contain only material of general interest (twelve per year—what would we call them?). The same correspondent suggested that specific nterest material be published in the TRANSACTIONS. The second letter deplored the use and existence of the TRANSACTIONS and, the writer felt, all material should be published in the PROCEEDINGS. Perhaps the present plan is the compromise which meets the need of most people!

Another correspondent struck a most responsive chord. He made an impassioned plea for the use of a consistent set of dimensional units for all PROCEEDINGS papers. A glance through several issues of the PROCEEDINGS validates his protest. As engineering writers we are certainly careless about dimensionality. In a given paper, on occasion, the same author mixes the English and the metric systems. This carelessness does not contribute either to smooth reading or to ease of continuity of interpretation. Without entering into the larger question of the ultimate adoption of the metric system in the United States (see, for example, page 584 of the April, 1959 issue of the PROCEEDINGS), it does seem that at least for scientific and technical articles, uniformity would be advantageous. Since the MKS system has been officially adopted, and all college and university text books have accepted the system, why not use it consistently in all engineering writing?

Another letter to the Editor has pointed out certain inconsistencies, to be deplored, in the use of abbreviations. What excuse is there, queries this communicator, for the small case "m," as an example, in "mc" as an abbreviation for megacycle and in "ms" as an abbreviation for millisecond? This complaint recalls the interesting article by Arnold P. G. Peterson, in the TRANSACTIONS ON ENGINEERING WRITING AND SPEECH, for December, 1959, in which he suggests a rational system for naming the prefixes for both positive and negative powers of ten, and he associates with each a suggested symbol. These suggestions avoid the difficulty quoted above by using capital letters as symbols, for positive values of the exponent of ten, and lower case letter symbols for the negative exponent.

These rambling comments, engendered by recent correspondence, emphasize the necessity for such a Professional Group as that on Engineering Writing and Speech; it behooves all IRE authors to make use of the opportunities this Professional Group offers for the improvement of their literary efforts. The Editorial Board is presently considering the revision and subsequent reissuance of the IRE document titled "Information for Authors." This brief document might well be supplemented ultimately by a more complete "style manual" produced in cooperation with the PGEWS.

Aftermath. Poles and Zeros in March took notice of the 1960 International Convention and Radio Engineering Show. In those comments attention was called to the Panel Session "Electronics—Out of This World" and now that the convention is history one reflects that much of it was "out of this world." To this observer a small sample of such reflections might be listed thus: opening ceremonies at the Coliseum contacted Pioneer V, already 1,449,000 miles from earth and going away at the rate of 6,000 miles an hour; components so minute that their containers must be labeled "This Box Is Not Empty;" solar powered electric automobile (1912 model), which prior to the convention operated in Central Park; the announcement of a search for intelligence coming from outer space at distances so great that the initiators may have been extinct for milleniums; passive satellite balloons ten stories high; eyes and brains too tired to take in more; possible clues to the diagnosis of muscular disease based on new ability to measure extremely weak high frequency electrical signals; miracles of microminiaturization—a one hundred tube digital computer the size of a cigarette box; the implantation of electronic equipment in the human body for periods up to five years; the use of electronic devices for prenatal diagnosis; etc., etc.; the largest attendance of all time totaling 69,760, exceeding 1959 by 15 per cent.—F. H., Jr.



Ferdinand Hamburger, Jr.

Editor, 1960

Ferdinand Hamburger, Jr. (A'32–M'39–SM'43–F'53) was born in Baltimore, Md., on July 5, 1904. He received the degrees of Bachelor of Engineering in 1924, and Doctor of Engineering in 1931, from The Johns Hopkins University, Baltimore, Md. He was a Charles A. Coffin Fellow in 1930–1931.

During the period between the undergraduate and graduate degrees he participated in a program of dielectric research at The Johns Hopkins University. In 1931 he was appointed instructor in electrical engineering, in 1947 professor of electrical engineering, and in 1954 chairman of the Department of Electrical Engineering, and in addition, in 1958 Director of the Radiation Laboratory of The Johns Hopkins University. He served as chief test engineer for Bendix Radio Division from 1942 to 1945, while on partial leave of absence from the University. He has acted as consultant for the Research and Standard Section, Bureau of Ships, Navy Department; U. S. District Court; RCA, and others. He has served as Research Contract Director of a number of research investigations supported by the Department of Defense at The Johns Hopkins University.

Dr. Hamburger was IRE Regional Director of the Central Atlantic Region in 1950–1951, and a Director-at-Large in 1959. He has served on the Nominations, Appointments, Policy Advisory, and Education Committees. He has been a member of the Editorial Board since 1956 and was Vice Chairman in 1958–1959. He was IRE representative at The Johns Hopkins University from 1941 to 1955. He was largely responsible for the formation of the Baltimore Section of the IRE in 1939 and its reorganization in 1944; he served as its Chairman in 1940–1941.

He is a Fellow of the American Institute of Electrical Engineers and is presently serving as Vice Chairman of its Instrumentation Division. He is a member of Sigma Xi, Tau Beta Pi, and Eta Kappa Nu, and is a registered Professional Engineer in the State of Maryland.

Scanning the Issue

Some Notes on the History of Parametric Transducers (Mumford, p. 848)—One would be hard put to name a subject which has caused more excitement in recent years than the parametric amplifier. What started as a small flurry of article writing a few years ago has since grown to near blizzard proportions. Well over 100 papers have been written on this subject in the last two years alone. Yet the parametric principle has been with us for many decades. Zenneck and Alexanderson described magnetic frequency doublers and magnetic amplifiers to IRE audiences 44 years ago. Indeed, this subject can be traced as far back as 1831 to Faraday's observations of the double period oscillation of surface waves of liquids. The history of the development of parametric principles and devices, from 1831 to the present, is briefly summarized in this excellent review of the subject. The chronology presented here, supported by 200 selected references, is little known and will do much to help readers orient in their minds the recent rash of new amplifiers having a common underlying principle.

Low-Noise Tunnel-Diode Down Converter Having Conversion Gain (Chang, *et al.*, p. 854)—A new and important use has been found for a device which is currently one of the most talked about components in the electronics field. As reported last July in the PROCEEDINGS, the tunnel, or Esaki, diode is a semiconductor device with negative resistance characteristics which give it exceptional high-frequency low-noise amplification capabilities. It is now shown that the nonlinearity of this negative resistance characteristic can be used for low-noise high-gain frequency conversion—from a high frequency to a lower frequency. This down-conversion capability is most significant. Although good up-converters have been developed recently, there is at present no mixer device capable of down-conversion that does not exhibit either a conversion loss or a poor noise factor. Thus the tunnel diode becomes the first device which can convert UHF or microwave signals to a lower frequency with low noise and conversion gain.

Noise Limitations to Resolving Power in Electronic Imaging (Coltman and Anderson, p. 858)—In recent years an increasingly large segment of the electronics profession has become concerned with the recognition of patterns on television and other cathode-ray-tube displays in the presence of noise. The study presented here of the limiting effects of noise on image resolution will be of fundamental interest to this group of readers. The authors show that the resolution limit can be accurately predicted in quantitative terms from a knowledge of noise power per unit bandwidth and the sine wave response of the system.

Packaged Tunable L-Band Maser System (Arams and Okwit, p. 866)—A maser normally requires cumbersome and highly precise supplementary equipment which limits its use to laboratory and a few other special types of installations. This paper describes a tunable maser system that has been packaged into a sufficiently compact form to make it suitable for field operational use without detriment to its low-noise performance. This "reduction to practice" of one of the important new developments in electronics will be of wide interest, especially to radio astronomers because its frequency range makes it suitable for studying the Doppler shift of the 21-centimeter hydrogen line in receding galaxies.

Cadmium Sulfide Field Effect Phototransistor (Bockemuehl, p. 875)—Cadmium sulfide has previously achieved fame as a photoconductive material. The author has now extended its utility by fabricating a cadmium sulfide transistor and obtaining useful power gain from it. This represents the first time that field effect amplification has been reported for any material in which virtually all the carriers are generated photoelectrically. Although CdS will never compete with germanium for general transistor applications, this work opens the door to many novel photocircuit functions which are not practicable with conventional circuit elements.

The Optimum Formula for the Gain of a Flow Graph, or a Single Derivation of Coates' Formula (Desoer, p. 883)—During the seven years since the first paper on the subject appeared in the PROCEEDINGS, signal flow graphs have become a popular and useful tool for analyzing a wide variety of engineering problems. This paper provides an important refinement of this tool—a new and simpler derivation of the gain formula for flow graphs. It has the added blessings of being a self-contained discussion of the subject and, in the author's words, being so simple "that even seniors can grasp it."

A Broad-Band Cyclotron Resonance RF Detector Tube (Turner, p. 890)—A novel method of detecting RF signals has been developed which utilizes the spiral motion of electrons as a tunable system which will become resonant when the frequency of spiraling is the same as that of an incoming signal. The tube is in essence a complete TRF receiver (less video amplifier) within one vacuum envelope. Its rapidly variable tuning and wide bandwidth (10 to 1) will make this development of considerable interest to engineers concerned with microwave systems for search, analysis and reception of signals over wide frequency ranges.

Anomalies in the Absorption of Radio Waves by Atmospheric Gases (Straiton and Tolbert, p. 898)—This paper will be of great interest to anyone concerned with propagation above 10,000 megacycles. The authors have gathered the results of recent propagation measurements in the millimeter range to shed new light on losses due to atmospheric absorption. They find that the measured losses in this relatively new part of the spectrum do not entirely agree with the losses predicted by classical theory developed over a decade ago, especially with respect to losses due to water vapor.

Interaction Impedance Measurements by Propagation Constant Perturbation (McIsaac and Wang, p. 904)—This paper is concerned with a technique for measuring the interaction impedance characteristics of microwave circuits by determining the change produced in the propagation constant when a rod is inserted in a waveguide. The technique is broadly applicable to various types of microwave structures, such as slow wave structures for traveling-wave tubes, and the results developed here will no doubt be regarded as a primary reference on the subject.

Taylor-Cauchy Transforms for Analysis of a Class of Nonlinear Systems (Ku, Wolf and Dietz, p. 912)—Since this paper is a companion to the paper that follows, the discussion of both papers have been combined below.

Laurent-Cauchy Transforms for Analysis of Linear Systems Described by Differential-Difference and Sum Equations (Ku and Wolf, p. 923)—This and the companion paper that precedes it describe a novel type of transform for solving problems described by linear and nonlinear differential and difference equations. The first paper, on Taylor-Cauchy transforms, deals with continuous nonlinear processes, while the second paper, on Laurent-Cauchy transforms, deals with discrete processes. They provide engineers with another tool of considerable usefulness in the analysis of a variety of physical systems.

Scanning the Transactions appears on page 965.

Some Notes on the History of Parametric Transducers*

W. W. MUMFORD†, FELLOW, IRE

Summary—**This paper summarizes briefly the chronology of the development of parametric transducers. The early works of Michael Faraday (1831), F. Melde (1859), and Lord Rayleigh (1883) are cited as mechanical examples and the pioneering work of L. Kühn, J. Zenneck, E. F. W. Alexanderson and R. V. L. Hartley are cited as electrical examples. A very brief résumé of selected contributions follows, dating from the work on H. Q. North's diodes in 1945 to the present flurry of excitement beginning in 1954, created by the development of the Signal Corps-Bell Laboratories Task 8 varactor diodes. A list of 200 selected references is included.**

THE recent interest in amplifiers which derive their gain from variable reactance circuit elements stems chiefly from the development of low-loss variable-capacitance diodes. There are two reasons for this interest. One reason is the fact that such amplifiers have low noise and the other is that the diodes are expected to have extremely long life. Either one of these properties is adequate justification for the excitement currently rampant throughout the world concerning the exploitation of this "new" type of amplifier, but, with two good reasons readily apparent, this excitation is doubled.

Mystery seemed to invade the thoughts of people when the scientists announced this new type of amplifier which was called a variety of names, such as: "Parametric Amplifier," "Reactance Amplifier" and "MAVAR" (Modulator Amplifier by Variable Reactance).[1] Some of this mystery could have been avoided had the modern men known or mentioned that the principle underlying the mechanism whereby electrical amplification was effected was an old principle. This principle may be broadly stated thus: *The energy of an oscillating system may be increased by supplying energy at a frequency which differs from the fundamental frequency of the oscillator.* One mechanical illustration of this principle is the simple pendulum. The child in the swing learns that he can "pump up" the amplitude of the oscillation of the swing by lowering his center of gravity on the down swing and raising it on the up swing. He thus "pumps" at twice the frequency of the swing. Who knows when this was invented? Could it have been in prehistoric times by a monkey swinging by his tail from the branch of a tree?

Faraday, Melde and Lord Rayleigh have published observations and calculations concerning this principle. Quoting Lord Rayleigh, "Faraday, . . . with great ingenuity and success (upon examining) . . . the crispations upon the surface of water which oscillates vertically, arrived at the conclusion experimentally that there were two complete vibrations of the support for each complete vibration of the liquid. Crispations (may be) observed upon the surface of liquid in a large wine glass or finger glass which is caused to vibrate in the usual manner by carrying the moistened finger round the circumference. All that is essential to the production of crispations is that the body of liquid with a free surface be constrained to execute a vertical vibration. Faraday's assertion that the waves have a period double that of the support has been disputed, but it may be verified in various ways." Faraday's work was published in 1831 and Lord Rayleigh verified his conclusions sixty years later, also with considerable ingenuity. The double period oscillation of the water is not readily proven by casual observation.

The following example of the principle, reported by Melde in 1859, is, however, readily observed and understood. Quoting again from Lord Rayleigh, "Perhaps the best known example is that form of Melde's experiment in which a fine string is maintained in transverse vibration by connecting one of its extremities with a vibrating prong of a massive tuning fork, *the direction of motion of the point of attachment being parallel to the length of the string.* Under these circumstances . . . the string may settle down into a permanent and vigorous vibration, whose period is the *double* of that of the fork." Lord Rayleigh analyzed and experimented with this and other similar mechanical phenomena in 1887. This led to analogous experiments with electrical circuits.

The electrical principle is readily understood by the following simple explanation. Suppose that we have a capacitor formed by two metal plates separated by air. Assume that a charge exists on the capacitor. The plates will be attracted to each other because of the equal and opposite charges so that to separate the plates requires work. Upon separating the plates, say to twice the original distance, the capacitance will be reduced to half its original value and, hence, the voltage must be twice the original value, since the charge upon the plates remains the same. The electrostatic energy, however, has been doubled, since it is proportional to the square of the voltage and directly proportional to the capacitance. The energy required to separate the plates now appears as electrostatic energy in the capacitor.

Now suppose that the capacitor is combined with an inductor to form an oscillating circuit. The voltage on the capacitor will reach a maximum value twice each cycle. Now if, on each half cycle, the capacitance is decreased when the voltage is maximum and increased when the voltage is zero, net energy will be imparted to the oscillations since no electrical energy is used to restore the capacitor to its original value when the voltage is zero.

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* Original manuscript received by the IRE, November 17, 1959; revised manuscript received, February 1, 1960.

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[1] These three names are considered herein to be synonymous and to apply to any device which derives its gain from the pumping of a variable reactance.

Similarly, it is apparent that energy could be imparted to the circuit had the *inductance* been varied in the appropriate phase. This electrical principle was expanded to include frequencies other than the two-to-one ratio and the resulting device was used successfully in radio telephone communication between Berlin and Vienna prior to World War I. This was described by L. Kühn in 1915. Prof. J. Zenneck, E. F. W. Alexanderson and R. V. L. Hartley pioneered with theoretical and experimental contributions within the next few years. Alexanderson called these devices "Magnetic Amplifiers," a name which remains with us today. The objective then was to modulate a continuous wave arc transmitter by means of a nonlinear inductance or saturable reactance. Here the voice currents constituted the signal, and the carrier was the pump. The resulting sidebands were radiated, together with the pump (or its harmonic in some cases).

I quote the following from a paper delivered by E. F. W. Alexanderson at an IRE meeting in New York City on February 2, 1916:

> The name "Magnetic Amplifier" has been given to a device for controlling the flow of radio frequency currents because this name seems to describe its function when it is used for radio telephony better than would any other. As the same device can be used for a variety of other purposes, the above name may in some cases not seem too appropriate. However, the essential part of the theory that will be given refers to the amount of amplification which is possible of attainment and the methods of securing a higher ratio of amplification than would be given by the device in its simplest form. . . .
>
> The ratio of amplification is proportional to the ratio between the frequency of the radio current and that of the controlling current.

(This conclusion was verified by R. V. L. Hartley and subsequently by Manley and Rowe.)

Alexanderson, in the discussion, also suggested amplification of incoming signals by cascaded stages of up-conversion, rectification and up-conversion, etc. The name of Alexanderson's device withstood the rigors of time. Currently, however, we recognize its radio frequency version as a type of parametric amplifier, reactance amplifier, or MAVAR.

In Alexanderson's magnetic amplifier, the chief interest resided in the mode of operation in which the input signal was in the voice frequency band and the useful output power was taken in some radio frequency band. Thus it was a modulator or up-converter.

Alexanderson presented curves to show that negative resistance effects could exist. Quoting again from his 1916 paper: Under some conditions "instability and generation of self-excited oscillations" can exist. "This is a condition that must be avoided for telephone control; whereas it may have useful applications for other purposes." (One useful application, pointed out by Eugene Peterson in 1930, was the negative resistance straight-through amplifier, in which the negative resistance effect was enhanced by the suppression of frequencies higher than the pumping frequency.)

Louis Cohen, in a communicated discussion of the paper, said:

> It appears to me that the fundamental principle . . . will find its application to other problems in connection with radio frequency circuits. One that suggests itself immediately is the amplification of incoming signals.

Alfred N. Goldsmith pointed out the advantages of Alexanderson's magnetic amplifier over the direct-current-controlled frequency doubler employed by Kühn.

Lee De Forest commented that the magnetic amplifier was far more practical as a high-power modulator than the ensemble of over 500 audion amplifiers used to obtain 11 kw at Arlington by the Western Electric Company. "No one can say, however, that the situation will not be altered very materially in one, two or three years after we learn how to build oscillions for large power outputs, say 5 or 10 kw each. That will create a very different situation."

Thus, there appears to be very old prior art on MAVAR, both as modulator and amplifier. However, the interest in magnetic amplifiers as radio frequency modulators subsided quickly with the advent of the high-power vacuum tube modulators. The "different situation" predicted by Lee De Forest in February, 1916, did, indeed, come to pass.

In the 1920's and '30's, interest developed in subharmonic oscillations in electrical circuits containing a variable reactance. These "parametric" oscillations could exist at any one of f/n frequencies, where n is the subharmonic fraction of the fundamental frequency. In 1954 Von Neumann and Goto independently recognized that a phase ambiguity existed in the subharmonic oscillations and that this ambiguity could be utilized in logic circuits. Goto calls this device a "parametron."

About thirty years after the pioneering work of Kühn, Zenneck, Alexanderson, and Hartley on inductive reactance modulators, interest developed in capacitance reactance modulators at microwave frequencies. The failure of reciprocity in some crystal converters observed in the middle 1940's by L. Apker of General Electric Co., Schenectady, N. Y., and R. N. Smith of Purdue University, Lafayette, Inc., and the peculiar behavior of welded contact germanium diodes made by H. Q. North of General Electric Co., Schenectady, N. Y., was interpreted to mean that the contact capacity varied with bias. H. C. Torrey of the Massachusetts Institute of Technology Radiation Laboratory, Cambridge, Mass., gave a thorough discussion of the theory of nonlinear capacity converters.

M. C. Waltz and R. V. Pound at the MIT Radiation Laboratory observed negative IF conductance when units like North's were used. Pound gave many interesting details about measured power and gain and also measured negative IF conductance. He obtained a 10-db gain and reasoned that such a receiver should have a better noise figure than that of a conventional converter which has conversion loss. He was unable, however, to achieve this.

In 1948, A. van der Ziel and, in 1949, V. D. Landon also derived the MAVAR gain relationships; the former also pointed out the low-noise figure possibilities.

In 1952, C. F. Edwards observed nonreciprocal behavior in converters when he used R. S. Ohl's bombarded silicon diodes which exhibited variable capacitance as well as variable resistance characteristics. This observation again triggered a sequence reminiscent of the North diode sequence of the 1940's in which Apker, Smith, Pound, and Waltz reported the experimental results and Torrey, van der Ziel, and Landon derived the theory. Corresponding names for the early 1950 sequence are Ohl, Edwards, Manley, and Rowe.

However, in neither of these sequences was a very low-loss variable capacitance diode available and hence the gain was limited and the noise figure was not especially good.

In 1954, the United States Signal Corps sponsored a project at Bell Telephone Laboratories, Murray Hill, N. J., to develop semiconductor devices. In the second interim report of this now famous "Task 8," A. E. Bakanowski published his derivation of the nonlinear capacitor as a mixer. The work of Bakanowski, Cranna and Uhlir led to the discovery of a technique for making low-loss units.

The technique of making low-loss silicon diode varactors or varicaps advanced rapidly and interest in these new units began to expand.

In the meantime, H. Suhl discovered that variable reactance in the microwave range was obtained in ferrite materials when properly excited by a pumping frequency. He proposed using this effect to obtain parametric amplification and discussed suitable materials in the paper published in 1957. M. T. Weiss verified Suhl's proposal experimentally.

M. E. Hines and H. E. Elder succeeded in demonstrating gain and oscillations in a reactance amplifier which used silicon varactors and suggested several microwave circuits for up-converters and negative resistance amplifiers. Their work stimulated activity in microwave applications of "varactor" diodes.[2]

In 1957, Heffner and Wade considered theoretically the noise, gain and bandwidth of parametric amplifiers.

Early in 1958, the low-noise properties predicted by theory were verified experimentally at the Bell Telephone Laboratories at 6000 mc by Uenohara and at 380 mc by Engelbrecht. Salzberg at Airborne Instruments Laboratory, Mineola, N. Y., and Heffner and Kotzebue at Stanford University, Stanford, Calif., also achieved low-noise performance working at 1 mc and 1200 mc, respectively.

Miyakawa in Japan, Cullen in England and Tien and Suhl in America considered the amplification and frequency conversion in propagating circuits in which the variable reactors were distributed along a transmission line while Bloom, Chang and Wittke of RCA Laboratories, Princeton, N. J., took up the theory of parametric amplification and discussed the new approaches to amplification of microwaves. Bloom and Chang also discussed the case of low frequency pumping.

R. S. Engelbrecht at Bell Telephone Laboratories designed a traveling wave UHF parametric amplifier using varactor diodes and achieved over 200-mc bandwidth at UHF with 8 to 10 gain. Measurements indicated an "astronomy" noise figure of one db, corresponding to a "radar" noise figure of about 3.5 db. (This compares favorably with the best commercially available vacuum tube, whose noise figure is about 5 db.)

In the meantime, Adler of Zenith, Chicago, Ill. (in June, 1957), suggested a novel principle of signal amplification using a pumped electron beam, and Bridges (in February, 1958) suggested and constructed a parametric amplifier using the variable reactance of a floating drift tube klystron. Louisell and Quate discussed the capabilities of this type of amplifier, and Adler demonstrated that the conclusions concerning the low-noise capabilities were indeed correct. He achieved a noise figure capability of 1.4 db, of which 0.4 db represented the loss in the input coupler.

The development of the vacuum tube in Alexanderson's time curtailed the interest in radio frequency parametric transducers. Thirty or so years later, the invention of the transistor then diminished the interest in vacuum tubes. But the interest in radio frequency parametric transducers was resurrected by the development of the low-noise variable capacitance diode, and this resurrection, in turn, has stimulated the interest in vacuum tubes as parametric transducers.

What is the next cycle in this see-saw pattern?

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Low-Noise Tunnel-Diode Down Converter Having Conversion Gain*

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Summary—**This paper describes the use of the new tunnel diode in a down converter. An experimental UHF circuit converting from a signal frequency of 210 mc to an intermediate frequency of 30 mc is used to illustrate the feasibility of this new converter. Conversion power gain of 22 db with less than 3 db noise has been achieved with gallium arsenide diodes. The circuit analysis proceeds from the basic nonlinear resistance of the tunnel diode I-V characteristic. Equations are developed for conversion gain, bandwidth and noise figure. From these equations, criteria are derived for the choice of diode characteristics and circuit parameters to obtain optimum performance.**

INTRODUCTION

THE low-noise, high-gain, conversion of a high-frequency signal to a lower-frequency signal has not been possible with previous mixer devices. Ordinary crystal mixers, which make use of the nonlinearity of their positive resistance, exhibit a conversion loss and a poor noise factor. The recently introduced parametric converters, which operate on a nonlinear capacitance or inductance basis, have achieved good noise factors with *up-conversion* gain. The parametric *down converters*, however, have poor noise factors. For such down converters, it is found that the excess noise factor (*i.e.*, the noise factor minus unity) varies roughly as the ratio of the input frequency to the output frequency. Thus, for a ten-to-one frequency down-conversion, the noise factor is around 10 db. Because of this frequency dependence, it is almost impossible to convert a microwave frequency into a low intermediate frequency with a reasonable noise factor by parametric converters.

The purpose of this paper is to report on a down converter using a tunnel diode (Esaki diode[1,2]) as the nonlinear resistance element. The fact that the negative resistance characteristic of a tunnel diode can be utilized to achieve low-noise amplification has already been demonstrated.[3] It is now shown that the nonlinearity of this negative resistance characteristic can be used for frequency conversion. Since the nonlinearity of a resistance, *not* a reactance, is utilized for frequency conversion, the noise factor is independent of the ratio of the input frequency to the output frequency. Thus, by using a tunnel diode, a low-noise down converter with conversion gain has been achieved.

ANALYSIS

The converter circuit to be analyzed is shown in Fig. 1, which also establishes the notation to be used in the following analysis. The three tank circuits which resonate at ω_1, the input signal frequency; ω_2, the difference frequency; and $\omega_3 = \omega_1 + \omega_2$, the local oscillator frequency, are coupled together by the tunnel diode.

The analysis proceeds in a manner entirely similar to that for the small signal nonlinear reactance case.[4] The I-V characteristic of the tunnel diode (Fig. 2) at the operating point P can be represented by a quadratic relation:

$$I = G_0 V - \mathcal{G} V^2. \tag{1}$$

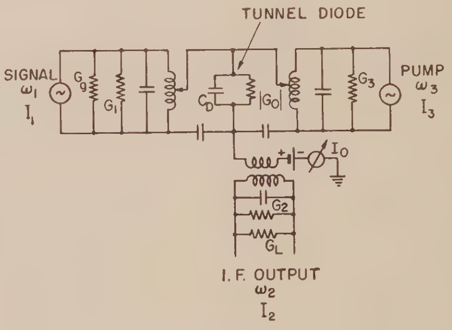

Fig. 1—Schematic diagram of converter circuit.

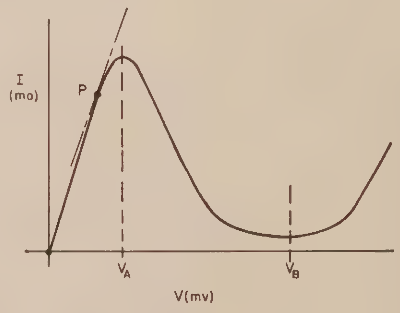

Fig. 2—Tunnel-diode I-V characteristic.

An operating point in the positive resistance region is chosen for reasons to be discussed later. The currents at the three frequencies are:

$$I_1 = V_1(\bar{G}_1 + j\bar{B}_1) - \mathcal{G} V_2^* V_3$$
$$I_2 = V_2(\bar{G}_2 + j\bar{B}_2) - \mathcal{G} V_1^* V_3$$
$$I_3 = V_3(\bar{G}_3) - \mathcal{G} V_1 V_2 \tag{2}$$

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* Original manuscript received by the IRE, December 14, 1959; revised manuscript received, February 16, 1960. This research was sponsored in part by the Electronic Res. Directorate, AF Cambridge Res. Center, under Contract AF 19-(604)-4980.

† RCA Laboratories, Princeton, N. J.

[1] L. Esaki, "New phenomenon in narrow Ge *p-n* junctions," *Phys. Rev.*, vol. 109, p. 603 (L); 1958.

[2] H. S. Sommers, Jr., "Tunnel diodes as high-frequency devices," PROC. IRE, vol. 47, pp. 1201–1206; July, 1959.

[3] K. K. N. Chang, "Low-noise tunnel diode amplifier," PROC. IRE, vol. 47, pp. 1268–1269; July, 1959.

[4] S. Bloom and K. K. N. Chang, "Theory of parametric amplification using nonlinear reactances," *RCA Rev.*, vol. 18, pp. 578–593; December, 1957.

where

$$\overline{G}_1 = G_1 + G_g + G_0$$

$$\overline{G}_2 = G_2 + G_L + G_0$$

$$\overline{G}_3 = G_3 + G_0$$

$$\overline{B}_1 = \omega_1 C_1\left(\frac{\omega}{\omega_1} - \frac{\omega_1}{\omega}\right)$$

$$\overline{B}_2 = \omega_2 C_2\left(\frac{\omega_3 - \omega}{\omega_2} - \frac{\omega_2}{\omega_3 - \omega}\right). \tag{3}$$

The small signal analysis neglects the effect of the nonlinear interaction on the local oscillator current. Hence, $\mathcal{G}V_1V_2$ is neglected in the third equation of (2).

In (3), G_1, G_2 and G_3 are the loss conductances of the respective circuits. These loss conductances consist of the circuit and the tunnel diode ohmic losses. The capacitances, C_1 and C_2, similarly consist of the circuit and tunnel diode capacitance, C_D.

A. Conversion Power Gain

The conversion power ratio under matched conditions is defined as

$$g_c = \frac{V_2^2 G_L}{\dfrac{I_1^2}{4G_g}}. \tag{4}$$

Solving (2), one obtains

$$g_c = \frac{4\mathcal{G}^2V_3^2G_gG_L}{[\overline{G}_1\overline{G}_2 - \mathcal{G}^2V_3^2]^2}. \tag{5}$$

Eq. (5) is a general expression for the conversion power ratio. When G_0 is positive, the ratio can be either greater or less than unity, depending on the I-V characteristic of the nonlinear conductance. In order to obtain a conversion gain (*i.e.*, $\sqrt{g_c} > 1$) with a positive G_0, it follows from (5) that

$$\sqrt{g_c} = \frac{2\dfrac{\mathcal{G}V_3}{G_0}}{\dfrac{1}{\sqrt{G_gG_L}}\left\{\dfrac{(G_g+G_1)(G_L+G_2)}{G_0} + G_1 + G_2 + G_0\left(1 - \dfrac{\mathcal{G}^2V_3^2}{G_0^2}\right)\right\} + \sqrt{\dfrac{G_L}{G_g}} + \sqrt{\dfrac{G_g}{G_L}}} > 1. \tag{6}$$

Since

$$\sqrt{\frac{G_L}{G_g}} + \sqrt{\frac{G_g}{G_L}} > 2 \tag{7}$$

when G_0 is positive, (6) is satisfied if

$$\frac{\mathcal{G}V_3}{G_0} > 1. \tag{8}$$

Eq. (8) is the necessary condition for gain. This equation shows, together with (1), that the I-V characteristic whose origin is at the operating point (such as P in Fig. 2) must exhibit a maximum value, and that the local oscillator voltage V_3 must be sufficiently large so that it swings the current below the value of the current at the operating point. In the case of an ordinary crystal detector, the I-V characteristic exhibits no such maximum and (1) and (8) can never be satisfied simultaneously. It is important to note that (8) can be satisfied when the operating point is chosen in the region where $V < V_A$ and where G_0 is positive.

For the region $V > V_B$, (8) still applies. In this region, however, the diode current is due to minority carriers and so it is probably not suitable for high frequency conversion.

For the region $V_A < V < V_B$, the G_0 is negative and stable biasing becomes critical. It is difficult to find a stable operating point without having the device break into spurious oscillations, because of the large voltage swing of the local oscillator.

In order to normalize the conversion power ratio (5), let:

$$\lambda = \frac{\mathcal{G}^2V_3^2}{\overline{G}_1\overline{G}_2} \tag{9}$$

$$Q_g = \frac{\omega_1 C_1}{G_g} \tag{10}$$

$$Q_L = \frac{\omega_2 C_2}{G_L} \tag{11}$$

$$\overline{Q}_1 = \frac{\omega_1 C_1}{\overline{G}_1} \tag{12}$$

$$\overline{Q}_2 = \frac{\omega_2 C_2}{\overline{G}_2} \tag{13}$$

$$\bar{g}_c = \left(\frac{Q_g}{\overline{Q}_1}\,\frac{Q_L}{\overline{Q}_2}\right) g_c. \tag{14}$$

Eq. (5) then becomes

$$\boxed{\bar{g}_c = \frac{4\lambda}{(1-\lambda)^2}}. \tag{15}$$

B. Bandwidth

Assuming that the half-power frequencies are near the resonant frequency, the following approximation can be made:

$$\overline{B}_1 = \omega_1 C_1\left(\frac{\omega}{\omega_1} - \frac{\omega_1}{\omega}\right) \doteq 2(\omega - \omega_1)C_1 \tag{16}$$

$$\overline{B}_2 = \omega_2 C_2\left(\frac{\omega_3 - \omega}{\omega_2} - \frac{\omega_2}{\omega_3 - \omega}\right) \doteq 2(\omega_1 - \omega)C_2. \qquad (17)$$

By defining the relative bandwidth as $B_1 = \Delta f_1/f_1$ and defining

$$S_1 = 2\overline{Q}_1 B_1 \qquad (18)$$

and

$$c = \frac{\overline{Q}_2\omega_1}{\overline{Q}_1\omega_2}, \qquad (19)$$

one obtains

$$S_1{}^2 = \frac{[2c(1-\lambda) - (1+c)^2] + \sqrt{[2c(1-\lambda) - (1+c)^2]^2 + 4c^2(1-\lambda)^2}}{2c^2}. \qquad (20)$$

For the case of high gain, *i.e.*, $\lambda \doteq 1$, (20) becomes

$$S_1 \doteq \frac{1-\lambda}{1+c} \doteq \frac{1}{1+c}\,\frac{2[\sqrt{1+\bar{g}_c} - 1]}{\bar{g}_c} \qquad (21)$$

and the voltage gain-bandwidth product is

$$\boxed{\sqrt{\bar{g}_c}\, B_1 \doteq \frac{1}{1+c}\,\frac{1}{\overline{Q}_1}}. \qquad (22)$$

C. Noise Figure

The noise figure can be found by considering the currents in (2) to be due to the thermal noise sources of the circuits:

$$|\mathcal{I}_1|^2 = 4k\Delta f(G_g T_0 + G_1 T + G_e T)$$

$$|\mathcal{I}_2|^2 = 4k\Delta f(G_L T + G_2 T + G_e T) \qquad (23)$$

where

k = Boltzmann's constant,
T_0 = reference temperature (290°K),
T = ambient temperature,
G_e = equivalent shot noise conductance of the tunnel diode,
$G_e = eI_0/2kT$, I_0 = dc current of the tunnel diode, and
$|\mathcal{I}|$ = equivalent noise currents.

Eq. (2) can then be written as:

$$|\mathcal{I}_1|^2 = |V_1\overline{G}_1 - \mathcal{G}V_2{}^*V_3|^2$$

$$|\mathcal{I}_2|^2 = |V_2\overline{G}_2 - \mathcal{G}V_1{}^*V_3|^2$$

$$|I_3|^2 = |V_3\overline{G}_3 - \mathcal{G}V_1V_2|^2. \qquad (24)$$

From the definition for the noise figure, one obtains

$$F = \frac{P_{\text{in}}}{P_{\text{out}}}\,\frac{N_{\text{out}}}{N_{\text{in}}} = \frac{1}{g_c}\,N_{\text{out}}\,\frac{1}{kT_0\Delta f} = \frac{|V_2|^2 G_L}{g_c k T_0 \Delta f}. \qquad (25)$$

After solving (24) for $|V_2|^2$ and substituting, (25) becomes

$$\boxed{F = 1 + \frac{T}{T_0}\left[\frac{G_e}{G_g} + \frac{G_1}{G_g} + \frac{(G_L + G_2 + G_e)\overline{G}_1}{G_g\overline{G}_2}\,\frac{1}{1 - \dfrac{2(\sqrt{1+\bar{g}_c} - 1)}{\bar{g}_c}}\right]}. \qquad (26)$$

EXPERIMENTAL RESULTS

An experimental circuit based on Fig. 1 and using coaxial lines has been built. The operating frequencies were $f_1 = 210$ mc, $f_2 = 30$ mc, and $f_3 = 240$ mc. Representative results are shown in Table I, and compared with computed values.

Figs. 3 and 4 show typical curves of the I-V characteristic of the germanium and gallium arsenide tunnel diodes that were used in the experiments in Table I. The germanium diode had a peak current of 35 ma at 62 mv; its operating point was chosen at 18 ma and 29 mv yielding a positive $G_0 = 0.42$ mho. The gallium arsenide diode had a peak current of 23.6 ma at 100 mv; the operating point was at 20 ma and 60 mv with a positive $G_0 = 0.20$ mho.

To complete the calculations according to (15), (22), and (26), it is necessary to know the values of certain circuit parameters. For the case of the experimental circuit of Fig. 1, the following values were measured. The values of λ were chosen to give agreement with measured gain ratios.

Germanium Diodes: $\lambda = 0.43$ $c = 0.1$ $\overline{Q}_1 = 100$ $G_g = G_L = 4$ mhos $G_1 \doteq G_2 \doteq 0$ $G_e \doteq 20I_0 \doteq 0.36$ mho: $G_0 = 0.42$ mho.

Gallium Arsenide: $\lambda = 0.88$ $c = 0.1$ $\overline{Q}_1 = 100$ $G_g = G_L = 4$ mhos $G_1 \doteq G_2 \doteq 0$ $G_e = 0.40$ mho $G_0 = 0.21$ mhos.

TABLE I

Diode	Power Gain		Bandwidth		Noise Figure		Sensitivity
	Measured	Computed	Measured	Computed	Measured	Computed	Measured
Germanium	6.0 db	6.0 db	0.9 mc	0.6 mc	5.2 db	4.4 db	1.5 μv
Gallium arsenide*	22.7 db	22.7 db	0.15 mc	0.26 mc	2.8 db	3.8 db	0.25 μv

* The gallium-arsenide diode is an experimental sample developed by A. Wheeler of the Advanced Development Group of RCA Semiconductor Division, Somerville, N. J.

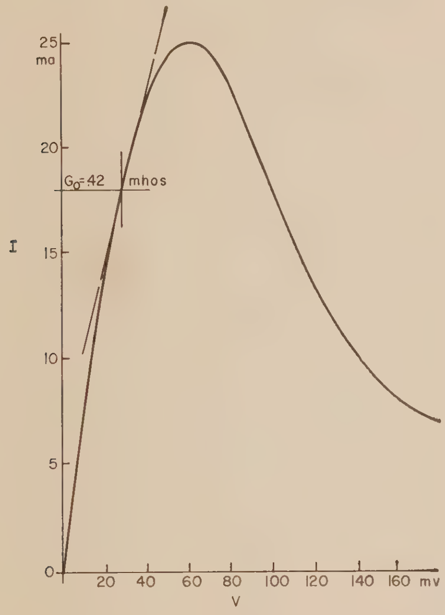

Fig. 3—Germanium tunnel diode.

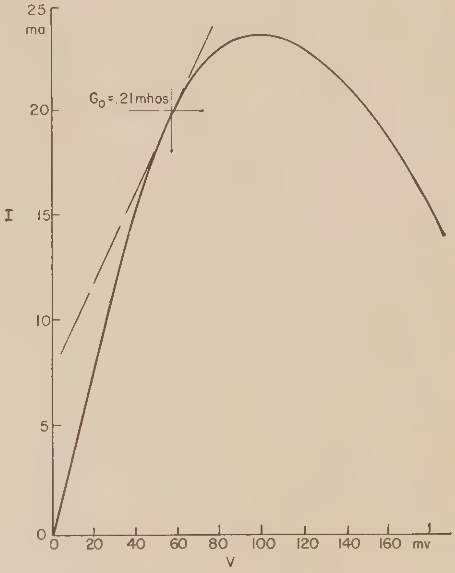

Fig. 4—Gallium arsenide tunnel diode.

Discussion

It is noted from Figs. 3 and 4 that the operating points for the diodes were chosen at a region where the slope of the I-V characteristic is positive. These operating points were established by the initial dc current from the bias supply and the rectified RF current of the local oscillator.

Conversion gain will result for positive G_0 when the requirements of (1) and (8) are met simultaneously (see Fig. 5). $\mathcal{G} V_3$ will be larger than G_0 when the RF voltage swing of the local oscillator is large enough to drive across the peak of the I-V curve and into the negative slope region until the instantaneous values of the current are smaller than the dc current at the operating point.

However, any appreciable voltage swing into the negative slope portion will make the system unstable, particularly when the negative slope is very steep. For this reason, it is more difficult to obtain high gain with germanium diodes, where the negative slope is much steeper, than for gallium arsenide. Had it not been for this stability problem, the germanium diodes would have yielded the same low-noise figure as the gallium arsenide diodes.

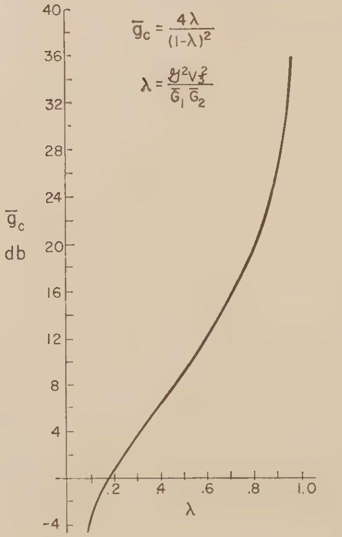

Fig. 5—"Normalized" conversion power ratio.

Further consideration of (22) and (26) will show the theoretical approach to optimum bandwidth and noise figure (Figs. 6 and 7). For improved bandwidth, the parameter c should be made small and the circuit's Q values should also be made small. Since $\bar{Q}_1 = \omega_1 C_1 / \bar{G}_1$, this immediately suggests that the circuit capacitances and

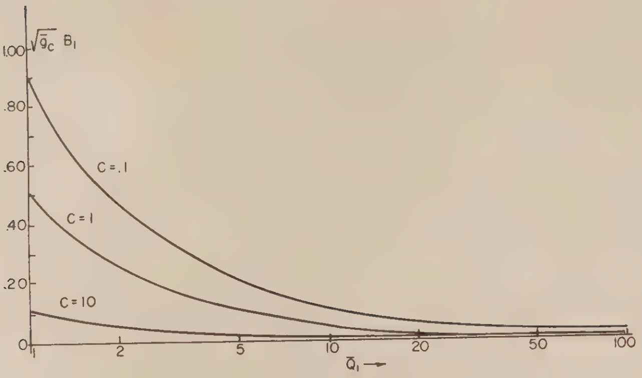

Fig. 6—Gain times bandwidth vs circuit Q for various

$$C = \frac{\bar{Q}_2}{\bar{Q}_1}\frac{\omega_1}{\omega_2}.$$

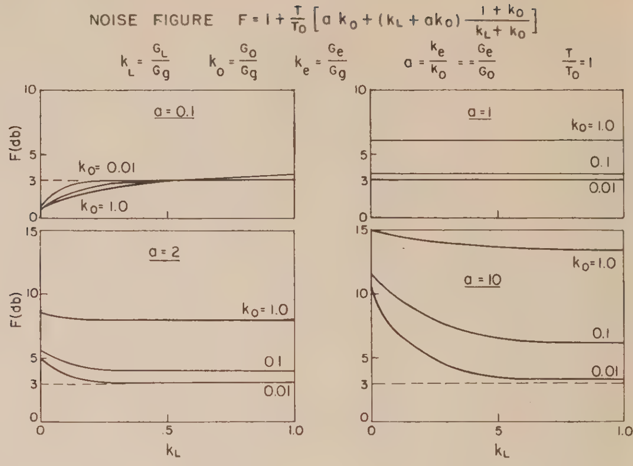

Fig. 7—Noise factor as a function of diode and circuit conductances.

especially the diode capacitance C_D should be made as small as possible. For a similar reason, G_g should be made larger than G_e to yield a low-noise figure.

The possibility of obtaining conversion using a lower pump frequency is to be noted. In this case, the nonlinearity of the diode characteristic could be used to produce the desired harmonic of the lower pump frequency for mixing. It is also noted that the possibility of making the diode-pump circuit self-oscillatory exists. Thus, direct down conversion can be obtained without a separate local oscillator.

Conclusions

The present experiments have demonstrated that the tunnel diode can be utilized as a *low-noise, high-gain down converter* in the UHF range. It seems feasible to extend the operating frequencies into the microwave region. The diodes for such applications should be designed with as low a capacitance as possible. The associated circuits, and especially the input circuit, should have high conductance and low Q's in order to realize optimum bandwidth and noise figures.

Noise Limitations to Resolving Power in Electronic Imaging*

J. W. COLTMAN† AND A. E. ANDERSON†

Summary—**A theoretical derivation, verified by experiment, shows that the maximum visible line number of a displayed bar pattern is directly proportional to the signal-to-white-noise ratio. The constant of proportionality and the effect of finite screen boundaries have been experimentally determined. It is found both theoretically and experimentally that the masking effect of white noise depends only on the noise power per unit bandwidth, and is independent of the upper frequency limit of the noise spectrum, provided that this exceeds the frequency limit set by the eye.**

These results can be used together with the aperture response of any imaging system to predict in quantitative terms the resolution limit as a function of the signal and noise levels. As an example, the theorems postulated are used together with the measured amplitude response function of the 5820-image orthicon to obtain a universal resolution vs signal-to-noise ratio curve for beam-noise-limited tubes of the image orthicon type. The predicted performance is in good agreement with experimental results. A similar set of curves for quantum-noise-limited image tubes is also given. The effects of object contrast variation, signal integration in time, and the presence of spurious background are presented.

I. Introduction

In recent years, there has been a widening interest in electronic imaging devices whose capabilities, with respect to sensitivity or spectral response, lie beyond that of the unaided eye. Television techniques, which permit arbitrarily high brightness amplification and contrast intensification, essentially remove most limitations of the human eye, so that performance is limited only by two system characteristics, the fidelity with which the image is reproduced, and the noise introduced into the information-bearing channel.

This paper deals quantitatively with the manner in

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* Original manuscript received by the IRE, November 17, 1959.

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which system noise interferes with image resolution. In the first section, there are derived, from pure scaling arguments, some completely general relationships between visual image detectability and noise intensity. These relationships are then particularized to the case of television presentation, and some experimental data in verification of the theory are presented. In the second section, it is shown how deterioration of the signal for fine patterns, together with the previously established demands on signal-to-noise ratio, combine to set a quantitative limit on resolving power.

II. Noise Considerations

A. Signal-to-Noise Ratio Required for Detection of an Image

The ability of the eye to distinguish a pattern in a noisy signal has been previously investigated[1,2] for cases in which the noise was assumed to result from the quantum nature of the signal itself. The formulation is ordinarily in terms of pattern contrast and population of events (light or X-ray quanta) giving rise to the noise. In the case being treated here, and indeed in essentially all cases of television presentation, one deals with a different situation, where there is an additive noise independent of the signal strength, and the final image contrast, brightness, and magnification can be adjusted at will by the observer. This paper establishes image detection limits which are independent of these last named quantities. Limiting resolutions are expressed solely by the signal-to-noise ratio as measured at some critical point in the system.

It is possible to derive certain relationships between image detail and signal-to-noise ratio required without recourse to any experiment. The argument which follows is not restricted to television-type displays, but, subject to the postulates given, applies to any display whatever.

This thought experiment is best conducted by first postulating a viewing screen, infinite in extent, producing light at an average brightness B, which fluctuates in time and space. Let the nature of this fluctuation correspond to "white" noise, that is, the light flux L per steradian from any area A has an average value AB and is distributed in a Gaussian fashion with a standard deviation $\Delta L = m\sqrt{AB}$. (This kind of "noisy" illumination is typified, for example, by an area emitting light in the form of uniform flashes, randomly distributed in time and space.) No particular value of m need be assumed, *i.e.*, it is permissible to subtract a constant value B_0 from the average brightness or to change the gain of the system, provided that the occurrence (mathematically speaking) of a negative value of light flux is a very rare event in any area of practical interest.

A viewer stands before this screen, and an operator superimposes on the noisy background described above a signal image of specified form and size. The operator then slowly reduces the signal strength until the image is no longer visible to the observer. During this process, the observer is free to change his viewing distance, add or subtract a constant brightness B_0 (subject to the condition mentioned above) and change the "gain" of the system, which operates on both the signal and noise alike. These are the operations known as "contrast enhancement" in a television system. Eventually, a value of signal will be reached which no longer permits the image to be distinguished in the noise, in spite of optimum adjustments on the part of the viewer. This is the threshold signal for the particular image and noise chosen, which we call Condition I.

Now three changes are made. The operator makes the image larger by a factor g, while the signal strength is left constant. He also increases the strength of the noise $m\sqrt{AB}$ by a factor g, to $gm\sqrt{AB}$. The viewer meanwhile is asked to increase his viewing distance by the same factor, g, and to leave all other parameters fixed. This is Condition II.

It is evident that the signal image is unchanged as far as the viewer is concerned; the increased viewing distance exactly compensates for the increase in pattern size, while the average apparent brightnesses, being independent of viewing distance, are fixed. What about the apparent fluctuation? This is unchanged also. In Condition I, an area A on the screen is projected to some area A' on the observer's retina. Under Condition II, this same element A' encompasses an area g^2A on the screen, because of the increased viewing distance. The operator has also changed the strength of the noise by a factor g, so that the standard deviation in the light flux per steradian corresponding to the area A' is now $gm\sqrt{g^2AB} = g^2m\sqrt{AB}$. The solid angle subtended by the observer's pupil is, however, less by a factor g^2, so we find that the fluctuation in brightness for any area A' on the observer's retina is exactly as in Condition I.

Thus, the visual effect received by the observer in Condition II is identical in all respects to that of Condition I. Since Condition I was an optimum as far as viewing distance, gain, and background brightness were concerned, then Condition II must also be an optimum, and represents again a threshold. Referring back to the changes made by the operator at the screen, we infer: *The strength of white noise required to mask an image signal is directly proportional to the linear size of the image.*

Because it is assumed that the viewer can change at will the gain, background brightness, and viewing distance, it is apparent that only the signal-to-noise *ratio* is important in determining the threshold. We may thus restate the results: *The signal-to-white-noise ratio required for detection of an image is inversely proportional to the linear dimension of the image.*

A corollary of the above may also be inferred from the

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[1] A. Rose, "Sensitivity of the human eye on an absolute scale," *J. Opt. Soc. Amer.*, vol. 38, pp. 196–208; February, 1948.

[2] J. W. Coltman, "Scintillation limitations to resolving power," *J. Opt. Soc. Amer.*, vol. 44, pp. 234–237; March, 1954.

same argument: *The optimum viewing distance for detection of an image in white noise is directly proportional to the image size.*

B. Signals and Noise in Television Displays

In deriving the theorems of Section II-A, noise was specified only by the constant m in the expression $m\sqrt{AB}$ and the image size by a linear dimension. In the television case, it is more convenient to measure the signal and noise in the electrical channel prior to conversion to a pattern, and to use for a standard of length the width of the frame of the picture. For convenience in the derivations which follow, it is assumed that the light produced on the kinescope face is directly proportional to the impressed signal. While this is not the case in practice, the threshold signals with which we deal are small, and since the "gamma" of the kinescope acts on signal and noise alike, the effect of the kinescope nonlinearity is equivalent, in the first order, to a simple change in system gain.

Assume a television image of a vertical sine wave bar pattern, having enough lines showing in the picture so that the effect of the finite frame size may be ignored. The theorem proposed states that the threshold signal-to-noise ratio is inversely proportional to the linear dimension of the image, or proportional to the number of lines N per cm.

$$N_{\text{threshold}} = \text{const}\left(\frac{\text{screen signal}}{\text{screen noise}}\right)\text{lines/cm.} \tag{1}$$

In (1) the screen noise is measured by the brightness fluctuation on some small area of the screen. It remains to relate this fluctuation to the noise impressed on the scanning beam.

Let the scanning beam current be i_0 and let it fluctuate with a noise of rms value i_n, measured over the bandwidth Δf. Consider an area A on the picture, small compared to the frame size but large enough to contain several resolution elements. In a time t larger than several frame times, there will be deposited in this area a total charge $q=(A/A_0)i_0t$, where A_0 is the frame area, or, more accurately, an extended frame area which takes account of the blanking and return times of the scans. This value of q will vary due to the fluctuation in i, but the fractional variation will be much smaller than that of i, because there are many samples of the beam current going to make up q. In measuring the noise current over a bandwidth Δf, we have effectively sampled the beam current by collecting charge over short times $1/2\Delta f$ in duration. In measuring q, however, the beam spends a time $(A/A_0)t$ in the area A, so that q contains $(A/A_0)2\Delta ft$ independent samples of the beam current. The fractional variation in q compared to that in the beam is reduced by the square root of this number. Thus

$$dq/q = (2\Delta ftA/A_0)^{-1/2}i_n/i_0. \tag{2}$$

The screen signal is related to q by a modulation factor which is the same as that for the beam current. Therefore

$$\frac{\text{screen signal}}{\text{screen noise}} = (2\Delta ftA/A_0)^{1/2}\left(\frac{\text{signal}}{\text{noise}}\right), \tag{3}$$

where both the signal and noise in the right-hand member are measured as currents or voltages in the electrical channel. It should be emphasized here that Δf is not necessarily the bandwidth of the system, but represents merely the frequency interval over which the noise was measured. It will be recognized that for white noise, the noise is directly proportional to $\sqrt{\Delta f}$, so that $\sqrt{\Delta f}$/noise is a constant independent of the bandwidth chosen, and is a measure of the spectrum level of the noise.

Combining (1) and (3),

$$N_{\text{lines/cm}} = \text{const}\,(2\Delta ftA/A_0)^{1/2}\left(\frac{\text{signal}}{\text{noise}}\right). \tag{4}$$

If the width of the displayed picture is W cm, the number of lines per picture is NW, and if A_0 is replaced by HW/e_ve_h, where H is the height and e_v and e_h are the sweep efficiencies, then (4) can be written as

$$N_{\text{lines/picture}} = k\left(\frac{Ate_he_v\Delta f}{R}\right)^{1/2}\frac{\text{signal}}{\text{noise}}, \tag{5}$$

where R is the aspect (height to width) ratio. Note that only this factor and the sweep efficiencies enter; the expression is independent of the number of scanning lines or the frame rate of the system.

It will be noted that in the derivation of (2) it was required that the minimum sample area A extend far enough to encompass several independent samples of i_n; *i.e.*, in terms of the television scan it must be several times wider than the resolution element set by the bandwidth. If the pattern detail is sufficiently large so that the eye can integrate over such an elemental area without decreasing the pattern contrast, then (5) can be expected to hold.

Now, if the noise in question arises, as is usually the case, from a white noise source located prior to the bandwidth-limiting circuits of the system, the noise current is itself proportional to $\sqrt{\Delta f}$. Eq. (5) in this case implies that *the threshold value for signal recognition is independent of the system bandwidth.*

The requirement on the sample area A noted above, and the use of an integrating time t larger than the frame time, is essentially equivalent to assuming that the eye, and not the system, sets the bandwidth. Since it is probable that the eye does not curtail the bandwidth sharply, pattern detectability may decrease somewhat as the bandwidth is gradually increased over the minimum required. Eventually, however, pattern detectability will become constant and independent of further increases in bandwidth.

The fact that the spectrum level of white noise required just to perceive the noise itself is independent of the noise bandwidth, is discussed by Mertz.[3] In that work, he finds a square "sampling area" for the eye of about 5 minutes of arc in linear dimension; this is consistent with the optimum viewing distance indicated in Fig. 3.

C. Experimental Determination of the Visibility Thresholds for a Bar Pattern

To test the relationships derived in the previous section, an experimental investigation of the visibility of sine wave bar patterns was carried out using a television monitor displaying accurately-measured sine wave signals and white noise. It should be noted that television kinescopes do not, in general, respond linearly (in light flux) to the voltage applied to the grid, so that we depart in this respect from the conditions postulated in the theory. For small signals and noise, this lack of linearity is of no consequence, as it merely introduces an extra gain in the system. For large signals, the noise will no longer be Gaussian. The extent of the departure from theory is left for experimental determination.

A block diagram of the equipment is shown in Fig. 1. The noise source was a temperature-limited thermionic diode, operating into a high-gain video amplifier. The amplifier characteristic was such as to give a noise power uniformly distributed within ±1 db from a few kilocycles to about 4.5 mc, with a rapid drop-off to a few per cent at 5.5 mc. The total curve could be approximated by a rectangular distribution extending to 5.0 mc. A coherent sine wave oscillator generated a sinusoidal bar pattern variable over the entire frequency band. An rms milliammeter with response flat to 8 mc was used to measure either the noise or the signal, which were then mixed and fed to the display kinescope. An attenuator was provided in the oscillator circuit to reduce the signal to any desired value. Brightness and contrast could be controlled on the monitor after the signals were measured and mixed.

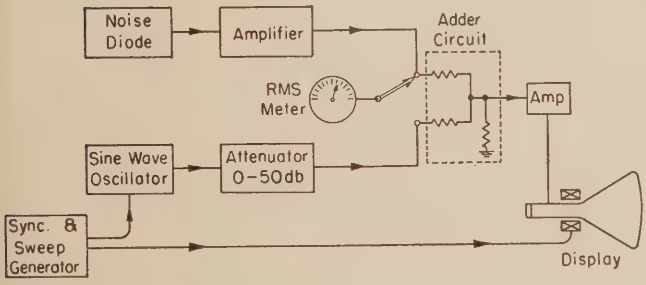

Fig. 1—Arrangement for displaying measured signals and noise. The synchronized sine wave oscillator produced a vertical sine wave bar pattern of variable intensity on the display, while a fixed measured white noise was superimposed.

The experimental procedure was to seat the subject before the television screen at a chosen distance, select a bar pattern of the desired number of lines (the number of line pairs per picture was taken as the number of cycles of the oscillator between blanking pulses, not all of which were visible on the screen because of masking) and set the noise and signal power equal by means of the noise meter. Correction was made for blanking periods, so the signal-to-noise ratios quoted represent those during the active period. The signal attenuator was then set to a value near the threshold of pattern visibility. The subject was asked whether or not he could discern the presence of the pattern, and after a "yes" or "no" response, the attenuator was reset to a neighboring value. At each condition, some 18 to 24 responses were requested, the attenuator being varied at random among three or four settings separated by 2 db. The setting (or interpolated setting value) at which the observer responded "yes" 50 per cent of the time was taken as the threshold of visibility. In almost all cases, a clean dividing line could be made, a typical situation being that in which six out of six responses were "yes" at 20 db, three out of six were "yes" at 22 db, and all were "no" at 24 db. Signal-to-noise ratios used in this paper are based on current rather than power, so that a 2-db step represents a 26 per cent change in signal current.

While an unequivocal result could usually be obtained in a single test, it was evident that an individual's threshold for a given set of conditions was not constant, but could vary by 50 per cent or more with time. Variations among individuals were also apparent. The amount of data taken was limited, and conditions of surround brightness, time interval between tests, etc., were not carefully controlled, so that the data presented here do not constitute a definitive study of this particular visual parameter. They suffice, however, to demonstrate the relationships derived above, to provide a numerical value of the constant k in (5), and to outline the area of validity of the theoretical treatment.

D. Experimental Results

Since the theory presupposes an optimum viewing angle for a given pattern, an attempt was made to establish this angle. With a fixed pattern, a single subject was tested at viewing distances ranging from $\frac{1}{4}$ to 7 meters. Several repeats at two meters were taken to check for uncontrolled shift of the threshold. Evidence of a considerable shift is given in Fig. 2, where threshold attenuator settings are plotted, not against distance, but against order number of the trials. The circled points are all for two meters. The points are labeled with the distance. In an attempt to extract some information, it was assumed that the threshold shift was gradual, and could be represented by the dotted line through the two-meter points. Deviations from this line by the other points were taken as representing a distance effect.

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[3] P. Mertz, "Perception of television random noise," *J. Soc. Motion Picture and Television Engrs.*, vol. 54, pp. 8–34; January, 1950.

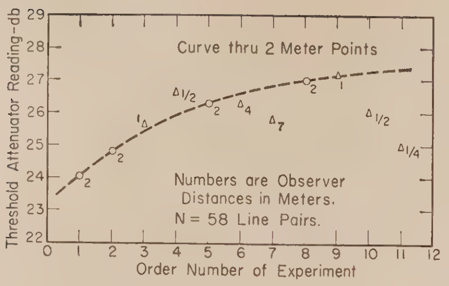

Fig. 2—Threshold readings taken at various distances as labeled on the points. Drift of the threshold is evident from the curve through the 2-meter points. All readings are with $N=58$.

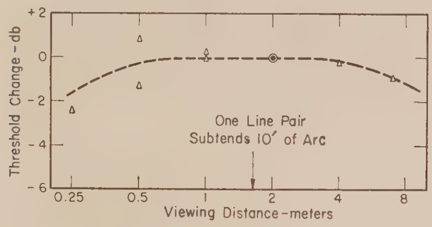

Fig. 3—Relative threshold as a function of viewing distance. Data are taken as the departure of points from the curve of Fig. 2. The extreme broadness of the optimum is evident.

The results are plotted in Fig. 3. There is some suggestion of an optimum near 1.5 meters, where one line pair subtends about 10 minutes of arc, but the most striking result is the broadness of the distribution. The effect of changing distance over a range of 30:1 is hardly outside the experimental error in determining the threshold. Thus, in succeeding tests, the subject assumed viewing distances roughly proportional to the pattern line width, but no attempt was made to control this factor rigidly.

The results of a series of runs using varying numbers of line pairs (cycles) per picture are given in Fig. 4. The solid line drawn with a 45-degree slope demonstrates the expected proportionality between line number and signal-to-noise ratio. It is of great interest to note the extremely small signal-to-noise ratios required, clearly showing the great extent to which integration takes place in the eye. From the position of this line and the 5.0-mc bandwidth used, we can evaluate the constant in (5) and write:

$$N_{\text{threshold}} = 615 \sqrt{\Delta f} \cdot (\text{signal/noise}), \qquad (6)$$

where Δf is measured in megacycles, and N is line pairs per picture width.

The earlier work on scintillation limited square wave bar patterns by Coltman[2] can be reformulated in terms of signal-to-noise ratio by calculating the noise power which the scintillations would generate in a circuit of bandwidth Δf, and taking account of blanking times and picture aspect ratio. When this is done, we arrive at the expression: $N = 640\sqrt{\Delta f} \cdot$ (signal/noise), which is in good agreement with (6). The constant in both cases is independent of the number of scanning lines and frame times, but will depend on the aspect (height to width) ratio and the fraction of the time spent in blanking, in the manner expressed by (5).

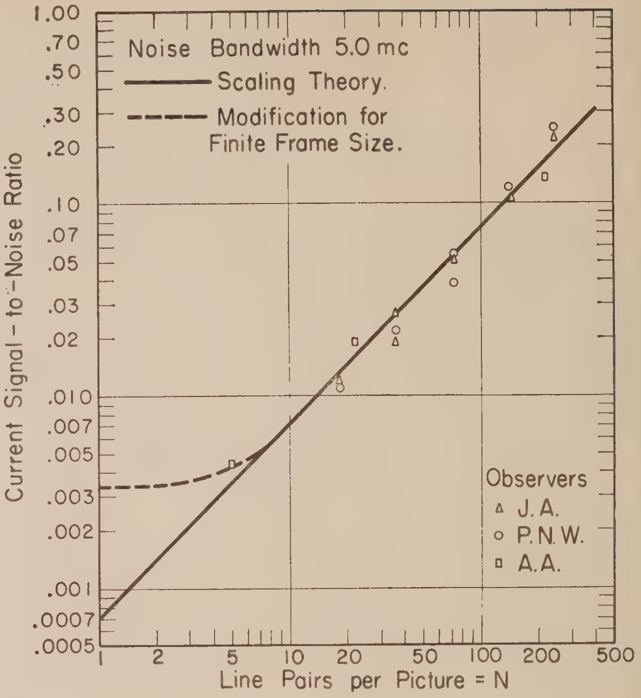

Fig. 4—Threshold signal-to-noise ratio as a function of number of cycles of the sine wave bar pattern displayed. The linear relationship extends over two decades, and departure is observed only for very small line numbers.

It is clear that while the scaling argument predicts a straight-line relationship over all values, the finite size of the screen will introduce departures for large line spacing. In order to determine the shape of the curve for very low numbers of line pairs per picture, a separate experiment was run. Here, the displayed picture was left fixed, and a series of cardboard aperture masks were employed to vary the number of lines seen by the observer.

The results, plotted in Fig. 5, show that the observer probably uses no more than seven line pairs in making an identification. As the number which he is permitted to see is decreased, the signal required rises rapidly, being greater by a factor of four when only one line pair is presented. The curve of Fig. 5 was used to draw the dotted lower portion of the curve of Fig. 4 by applying to the extension of the straight line the measured increase in signal required. A lower limit to the threshold signal-to-noise ratio for the largest complete sine wave pattern which can be shown is thus found to be about 1/300, where the noise is measured over 5 mc.

A fourth experiment was made to demonstrate the effect of bandwidth. A capacitor was arranged to be switched across the input circuit so as to reduce the bandwidth from 5 mc to about 600 kc. The total integrated noise power was thereby reduced by a factor of 7.6, and the rms noise current by a factor of 2.8. An 11-line pattern, whose frequency was so low as to be essentially unaffected by the bandwidth change, was dis-

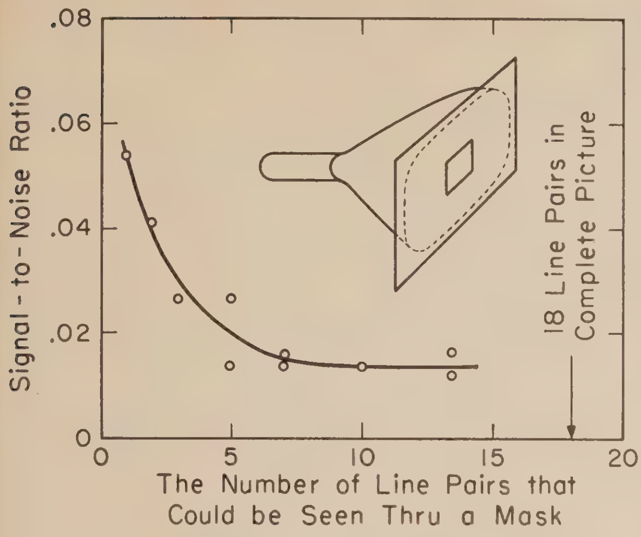

Fig. 5—Effect of frame limitation on signal-to-noise ratio required. These data were used to extend the curve of Fig. 4 to low line numbers.

played. Threshold measurements were taken while the capacitor was switched in and out at random intervals. It was found that the observer required 25 per cent less signal when the narrow bandwidth was used. While the shift was not zero, it was small compared to the large factor in noise current. This indicates that the over-all bandwidth was being set primarily by the eye, though it was still being affected somewhat by the system. A more carefully arranged experiment with sharp cutoff filters and optimum viewing distance for the observer would delineate more clearly the manner in which the eye can ignore high frequencies when looking for a low-frequency pattern.

III. ESTABLISHING THE RESOLUTION LIMIT

The theoretical and experimental information presented in Section II establishes the signal-to-noise ratio required to perceive a given line number. In many types of imaging systems, it is possible to determine by calculation what signal-to-noise ratio will be obtained, and this is also a function of line number. With these two pieces of information, one can determine quantitatively the resolution limit—the line number which can no longer be perceived by the eye—as a function of the input conditions and system parameters. A few cases which represent basic situations are discussed below.

A. Noise Independent of Signal

The signal current in the information channel will, of course, be a function of many system parameters. In particular, as a result of finite scanning apertures, electron-optical aberrations, etc., the signal response will diminish for fine patterns. It is convenient to describe this effect by the sine wave response function,[4] which

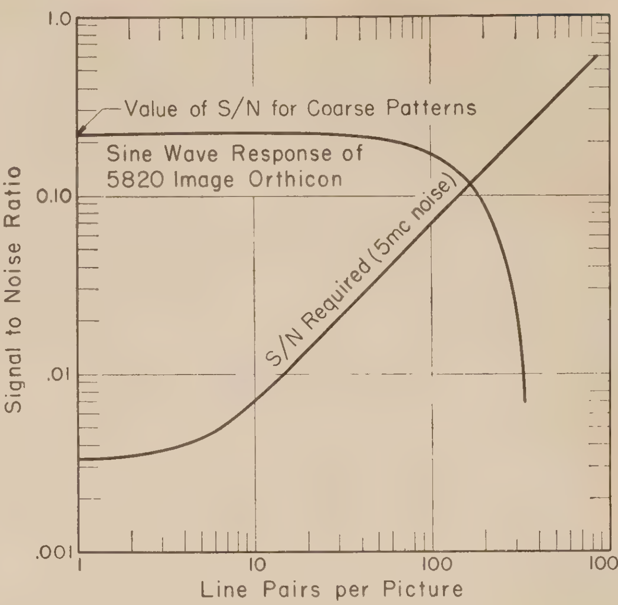

Fig. 6—Limiting resolution established by the intersection of curves representing available and required signal-to-noise ratio.

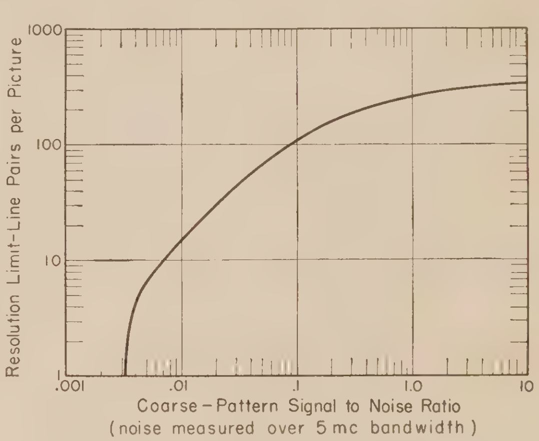

Fig. 7—Calculated resolution limit for a typical image orthicon as a function of the signal-to-noise ratio for large patterns.

gives the relative signal strength as a function of the space frequency of a sine wave test pattern. Such a response curve for a typical image orthicon is plotted as the upper curve in Fig. 6. The intercept at a signal-to-noise ratio of 0.22 is arbitrarily chosen for an example. The value is maintained essentially unchanged for low line numbers, and is called here the coarse-pattern signal-to-noise ratio. At higher line numbers the signal (and therefore the signal-to-noise ratio) diminishes as shown. Also plotted in Fig. 6 is the previously derived curve of Fig. 4 which establishes for each line number the threshold of signal-to-noise ratio. The abscissa of the intersection of the two curves gives the resolution limit corresponding to the coarse-pattern signal-to-noise ratio chosen.

By making a series of such choices, the curve of Fig. 7 is derived, which gives the resolution limit as a function of the coarse-pattern signal-to-noise ratio. The curve approximates over a decade a direct proportion between signal-to-noise ratio and resolution limit; it drops rapidly at the lower end due to the inability of the finite picture to display enough lines, while at the upper end it flattens out as the effects of finite focal spots reduce the available signal.

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[4] J. W. Coltman, "The specification of imaging properties by response to a sine wave input," *J. Opt. Soc. Amer.*, vol. 44, pp. 468–471; June, 1954.

It should be noted that these curves assume an electrical channel of flat response and wide bandwidth. The 5-mc band over which the noise is measured is used only to establish a numerical value for the signal-to-noise ratio. Both noise (assumed white) and signal may extend well beyond this limit.

For an image orthicon operated at low light levels, the noise is essentially fixed, so that the signal-to-noise scale can be replaced by a properly established scale of scene illumination. The conversion factor will be a function of the photo-surface response, the optics used, and the object contrast, but the shape of the curve will remain fixed. Experimental confirmation is afforded by some data taken by Hannam[5] on two image orthicons employing different target materials, giving the observed resolution as a function of illumination. These data have been plotted in Fig. 8 with the illumination scale shifted for each tube to obtain the best fit to the theoretical curve. Considering the semi-subjective nature of such measurements, the agreement is satisfactory.

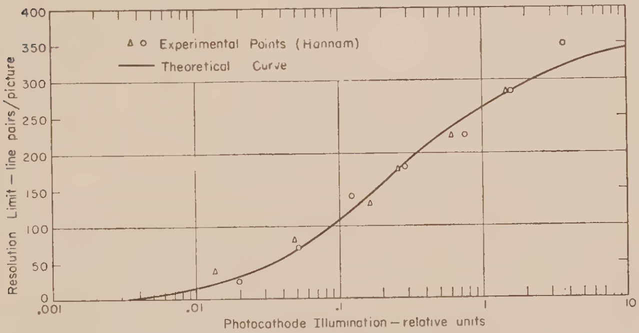

Fig. 8—Comparison of experimental and calculated resolution for two image orthicons.

B. Noise a Function of Signal

Optical imagining systems will finally be limited in detectivity by the quantum noise inherent in the light itself. The relationship between highlight illumination and resolution limit will no longer have the form of Fig. 7, since the noise is a function of the signal strength. The case of a signal pattern of 100 per cent contrast and a pickup system where no noise is introduced other than that associated with the quantum nature of the light represents the ultimate in detectivity. The coarse-pattern signal-to-noise ratio now becomes proportional to the square root of the signal itself. Rather than working in terms of a signal-to-noise ratio which remains to be measured on the particular equipment at hand, the results can be generalized by employing as an independent variable the number of quanta registered per unit time. This number will be directly proportional to the illumination on the scene, the constant of proportionality being determined by the effective size of the optical aperture and the dimensions and quantum efficiency of the receiving photosurface.

Let n be the number of photoelectrons ejected per second from the entire photosurface when it is uniformly illuminated at the level corresponding to the highlight scene brightness. If a sine wave pattern of 100 per cent contrast is then used as a test object, the peak-to-peak signal current during the scan is ne/e_he_v where e is the electronic charge and e_h and e_v the horizontal and vertical scan efficiencies. The corresponding rms signal current is $ne/\sqrt{8}e_he_v$. The average current $\bar{\imath}$, which is just half of the peak current, gives rise to an rms noise current equal to $\sqrt{2e\bar{\imath}\Delta f}$. The signal-to-noise ratio during the active portion of the scan is then:

$$\text{SNR} = \sqrt{n/8e_he_v\Delta f}. \tag{7}$$

In order to use the curves of Fig. 6 and Fig. 7, the values of $\Delta f = 5 \times 10^6$ and $e_he_v = 0.79$ corresponding to the test conditions are substituted, to yield

$$\text{SNR} = 1.80 \times 10^{-4}\sqrt{n}. \tag{8}$$

The validity of this procedure may be questioned for values of n such that less than one impulse is received in a half-cycle of the upper frequency of 5 mc. It is necessary again to point out that the 5-mc bandwidth assumed for the calculation of Figs. 6 and 7 is an arbitrary means of specifying the noise power per unit bandwidth of a white noise spectrum. Because the eye integrates in time and space, (7) is a valid transformation factor for relatively small values of n, even though it does not predict the result which would be obtained by measurement in the electrical channel with a wide-band noise meter. The correctness of this argument is borne out by the visual experiments by Coltman,[2] which show that the relationship (6) is followed for values of n at least as low as 1000 per second.

Using (8) and the curve of Fig. 7, it is possible to calculate the performance of a hypothetical imaging system whose optical fidelity is the same as that of the image orthicon, but which has no noise other than the inherent shot effect of the initial photoelectric surface. The relation between the resolution limit and the photoelectron emission rate for this case is shown as curve 1 of Fig. 9. It is extremely broad and extends to the remarkably low limit of about 400 flashes per second.

In practice, complete freedom from extraneous noise is an ideal rarely to be expected. For example, at room temperature, thermionic emission from the photoelectric surface will contribute a fixed electron emission rate which should be included in $\bar{\imath}$ in calculating the signal-to-noise ratio. If n_0 is the fixed emission rate which must be added to the rate $n/2$ due to the signal, we obtain as a modification of (8) the expression

$$\text{SNR} = 1.8 \times 10^{-4}\frac{n}{\sqrt{n + 2n_0}}. \tag{9}$$

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[5] H. J. Hannam, "Development of New Thin Film Targets for the Image Orthicon," U. S. ERDL, Fort Belvoir, Va., Third Quarterly Rept., Contract DA-44-009 ENG-3652.

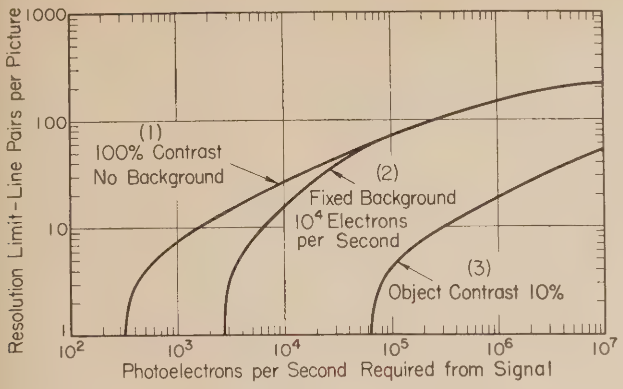

Fig. 9—Calculated resolution limits for cases where noise originates solely in the photocathode of an image orthicon type tube.

The effect of a fixed background emission of 10^4 electrons per second is illustrated by curve 2 of Fig. 9.

C. Effect of Contrast Reduction

While a 100 per cent contrast test pattern makes a convenient test object for specifying system performance, the scenes to be viewed in practice may often have relatively low contrast values. Contrast is defined here in terms of the highlight brightness, *i.e.*, for a sinusoidal test pattern, as follows:

$$C = (B_{\max} - B_{\min})/B_{\max}.$$

In the case where the noise is independent of the signal, loss of contrast simply means a corresponding loss of signal, so that the curve of Fig. 7 retains its shape while the scale of illumination is appropriately altered. Thus, in going from a 100 per cent to a 10 per cent contrast test pattern, the illumination must be increased by a factor of 10 to achieve the same resolution.

When the noise is due purely to the shot effect in the photosurface, a loss of contrast is attended by a similar loss of signal, but an increase of illumination to counteract this loss will also increase the noise. By a procedure similar to that used in the derivations of (7) and (9), a general expression is obtained which takes account both of fixed noise n_0 and contrast C, both referred to the maximum emission rate n due to the light alone, as follows:

$$\text{SNR} = 1.8 \times 10^{-4} \frac{nC}{\sqrt{n(2 - C) + 2n_0}} \cdot \qquad (10)$$

Curve 3 of Fig. 9 shows the relatively drastic effect of contrast reduction in the case of quantum noise only. A reduction of contrast from 100 per cent to 10 per cent now requires for compensation not ten times the illumination but 190 times. It will be appreciated, however, that the quantum noise is always present, and that the fixed noise case represents merely the situation where the additive noise is so large that it swamps out the quantum noise. When $n_0 \gg n$, (10) reduces to the case where the signal-to-noise ratio is directly proportional to the illumination and the contrast.

D. Effect of Integration in Time

The integration time of the eye is generally accepted to be approximately 0.2 second, a value which can be determined by comparing still photographs taken with various exposure times with impressions received of live pictures of noisy material. While this was not done quantitatively in the above work, some remarks on the expected effect of time integration may be appropriate. In a conventional television pickup system, light is collected for a time τ (1/30 second) before the information is scanned off and presented. If this time is lengthened to T the signal may be enhanced (in a properly operating storage medium) by a factor T/τ. If the noise arises solely in the subsequent system, it need not be presented to the eye during storage, and the visual signal-to-noise ratio is improved by a similar factor.

In the case of noise arising solely from the photoelectric shot noise, the situation is quite different. As long as the frame time is short compared to the integration time of the eye (0.2 second) the visual signal-to-noise ratio will be independent of the frame time or the duration of the individual flashes. Integration by storage means or by a long persistence phosphor will be effective only if it extends the integration time beyond that of the eye. The exact effect of added integration can be calculated only through a convolution of the decay characteristic of the eye with that of the storage system employed. However, a rule-of-thumb frequently employed in convolution processes indicates that the effective total integration time will approximate the square root of the sum of the squares of the two individual times. Thus the illumination required to achieve a given resolution will vary as

$$[(T/0.2)^2 + 1]^{-1/2},$$

where T is the system integration time in seconds. For values of T much less than 0.2 second, the illumination required is independent of T; for large values it is inversely proportional to T, so that the product of the illumination and the time, *i.e.*, the exposure, is constant.

CONCLUSIONS

For imaging systems whose output is viewed by the eye, and which are limited by white noise, the resolution limit can be predicted from a knowledge of two parameters, the noise power per unit bandwidth, and the sine wave response of the system. Because the demands on signal-to-noise ratio increase linearly with the line number, and the sine wave response usually falls off with at least the square of the line number, the resolution limit varies only slowly with signal input. The range of object illumination over which the resolution is appreciably varying may extend over several decades. In specifying the performance of systems designed to operate in the noise-limited region, it is thus highly desirable to give the entire resolution vs illumination curve, since neither the large-object detection limit nor the resolving power in the absence of noise (the two most frequently used characteristics) is a well-defined quantity.

Packaged Tunable L-Band Maser System*

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Summary—A low-noise tunable *L*-band maser system is described. The maser uses a pink ruby crystal oriented at 90° and is tunable from 850 to 2000 mc. The voltage-gain bandwidth product is as high as 37.5 mc at a liquid helium bath temperature of 1.5°K. An *L*-band circulator has been developed for use with the maser. It has an insertion loss of 0.3 db, operates over a 200-mc frequency range at *L*-band, and determines the usable tuning range of the circulator-maser system. The maser and circulator have been packaged into an operational unit that includes all auxiliary components, and has a system noise factor of 0.5 db (35°K). Electrical and mechanical features of the system are described and performance data are given.

I. Introduction

THE low-noise characteristic of the three-level solid-state maser amplifier has stimulated the interest of workers in a number of fields where the ultimate in receiver sensitivity is required. Radio astronomers, for example, are particularly interested in using a maser as a preamplifier for a 21-cm interstellar hydrogen-line receiver. Because of the Doppler shift in the frequency of the hydrogen line in receding galaxies, an *L*-band maser amplifier, which covers 1420 mc and tunes down in frequency, is of great practical interest. A packaged tunable maser system is described that tunes over a 200-mc frequency range at *L*-band.

Fixed-frequency *L*-band masers have been operated using chromium-doped potassium cobalticyanide.[1,2] Furthermore, gadolinium-doped hydrated lanthanum ethyl sulfate with cerium impurity[3] and chromium-doped aluminum oxide (ruby) had given satisfactory operation at higher microwave frequencies.[4–7] Ruby was chosen for our maser, because of its excellent physical, mechanical, and chemical characteristics, even though it had not previously to our knowledge been used as a material for *L*-band maser operation. Its characteristics include favorable "zero-field" splitting of the energy levels, good crystal line width, favorable relaxation times, low dielectric loss, machinability to accurate dimensions, resistance to cracking upon repeated temperature cycling, chemical inertness, and availability.

It was found[8] that *L*-band maser operation using ruby could be achieved, and satisfactory gain-bandwidth products obtained. In our design we placed emphasis on the feature of tunability. A tuning range from 850 to 2000 mc was obtained. Since a low-loss four-port *L*-band circulator was not available, such a unit, having a 200-mc frequency range for use with the maser, was developed.[9]

The maser and circulator were then packaged with the necessary auxiliary equipment to form a complete low-noise *L*-band preamplifier having a system noise factor of 0.5 db (35°K).

II. System Description

A schematic diagram of the maser system is shown in Fig. 1. The signal received by the antenna is directed by the four-port circulator into the single-port cavity maser; the amplified signal leaves the maser by the same

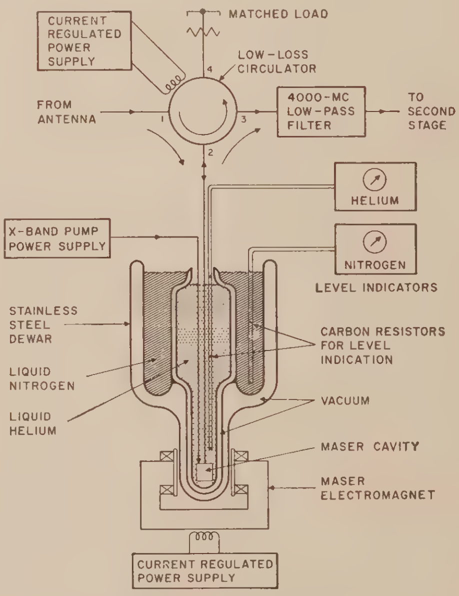

Fig. 1—Schematic diagram of maser system.

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* Original manuscript received by the IRE, August 19, 1959; revised manuscript received, December 21, 1959. This work was supported by the U. S. Department of Defense, and was presented at the 1959 PGMTT Symposium, Harvard University, Cambridge, Mass.; June 2, 1959.

† Airborne Instruments Lab., Cutler-Hammer, Inc., Melville, L. I., N. Y.

[1] J. O. Artman, N. Bloembergen, and S. Shapiro, "Operation of a three-level solid-state maser at 21 cm," *Phys. Rev.*, vol. 109, pp. 1392–1393; February 15, 1958.

[2] S. Autler and N. McAvoy, "21-centimeter solid-state maser," *Phys. Rev.*, vol. 110, pp. 280–281; April, 1958.

[3] H. E. D. Scovil, G. Feher, and H. Seidel, "Operation of a solid-state maser," *Phys. Rev.*, vol. 105, pp. 762–763; January 1, 1957.

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[5] R. W. DeGrasse, E. O. Schulz-DuBois, and H. E. D. Scovil, "Three-level solid-state traveling wave maser," *Bell Sys. Tech. J.*, vol. 38, pp. 305–334; March, 1959.

[6] T. H. Maiman, "Solid-state masers—design and performance," *Proc. NSIA-ARDC Conf. on Molecular Electronics*, Washington, D. C.; November 13, 1958.

[7] J. A. Giordmaine, L. E. Alsop, C. H. Mayer, and C. H. Townes, "A maser amplifier for radio astronomy at *X*-band," PROC. IRE, vol. 47, pp. 1062–1069; June, 1959.

[8] F. R. Arams, S. Okwit, and A. Penzias, "Maser action in ruby at 21 cm," *Bull. Amer. Phys. Soc.*, ser. II, vol. 4, p. 21; January 28, 1959.

[9] F. R. Arams, G. Krayer, and S. Okwit, "Low-loss *S*- and *L*-band circulators," 1959 IRE NATIONAL CONVENTION RECORD, pt. 3, pp. 126–133.

port and is directed by the circulator to the second stage. A low-pass filter having a cutoff frequency of 4000 mc is placed at the output of the maser system to prevent feed-through of pump power into the receiver. At this location, the filter will not adversely affect system noise factor.

A matched load is connected to the fourth port of the circulator. This load can be refrigerated if it is necessary to reduce its noise contribution caused by antenna mismatch (which reflects load noise into the maser).

The maser cavity (which is described more fully in Section III) is located near the bottom of a 2-inch inner diameter stainless-steel double Dewar flask. The inner portion of the Dewar flask is filled with $2\frac{1}{4}$ liters of liquid helium, which is allowed to enter the maser cavity. One charge of liquid helium yields approximately 16 hours of operation. The outer jacket of the Dewar flask is filled with liquid nitrogen to reduce liquid helium evaporation. The Dewar flask is constricted at the bottom to a $2\frac{1}{4}$-inch outer diameter to keep the dimensions of the maser electromagnet to a minimum. The maser electromagnet employs a 5-inch diameter pole-face and provides a magnetic field that is homogeneous within ±5 gauss out of 2000 gauss over the volume occupied by the ruby crystal.

Liquid level indicators are provided for the refrigerants. These use three carbon resistors connected in parallel and located at various heights in the Dewar flask. Liquid levels are displayed on two ammeters. A relay-actuated warning light indicates when a new charge of liquid helium is required.

The X-band pump power circuitry (shown in Fig. 2) consists of 1) a Varian X-13, 100-mw, klystron with a dial mounted on its tuning shaft that is directly calibrated in frequency, 2) an isolator that helps to stabilize the klystron by protecting it from load variations, 3) a variable attenuator that allows for pump power level adjustment, and 4) a 20-db bidirectional coupler to sample the pump output that is detected and displayed on a microammeter (this monitors the pump power level). The power reflected from the maser cavity is also sampled by the bidirectional coupler, detected, and fed to an oscilloscope to permit observation of the maser cavity resonance. For this purpose, the klystron is frequency-modulated using sawtooth modulation from the klystron power supply. A reaction frequency meter is included to permit accurate determination of pump frequency.

III. Tunable Maser Cavity Design

For maser operation, it is desirable that the cavity containing the paramagnetic material (ruby) be resonant at both the signal and pump frequencies. Furthermore, it is desirable that 1) these two cavity resonances be independently tunable, 2) the tuning be accomplished from the top of the Dewar flask while the cavity is in the liquid helium, and 3) the cavity coupling at the signal frequency be adjustable so that gain and bandwidth can be varied during operation.

The cavity design used, which meets all of these requirements, is shown in Fig. 3. This structure has the additional feature of simple mechanical design for making the required tuning and coupling adjustments.

The signal-frequency mode consists of a quarter-wavelength TEM-mode resonator.[1] This resonator is a thin-rod center conductor between parallel ground planes provided by the broad walls of a small X-band waveguide. This type of structure has the advantages that 1) resonant wavelength is proportional to rod length, 2) cavity coupling remains reasonably constant with frequency, and 3) the RF magnetic field distribution over the paramagnetic material remains essentially unchanged while the cavity is tuned. Because the TEM mode is dominant, the problem of spurious responses is minimized. A tuning range of more than one octave is obtained simply by varying the length of the center-conductor rod. The rod length is reduced by a factor of about three because of the high dielectric constant of the ruby. This is desirable at L-band to keep physical dimensions small. The unloaded Q of this structure is 550 at room temperature and increases to 1100 at 4.2°K.

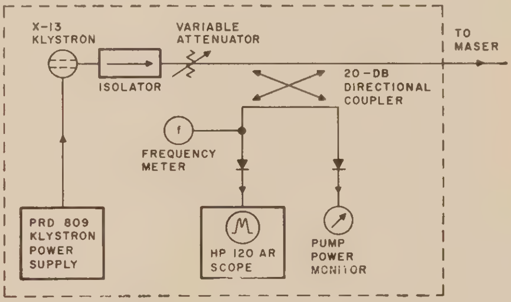

Fig. 2—Schematic diagram of X-band pump power supply.

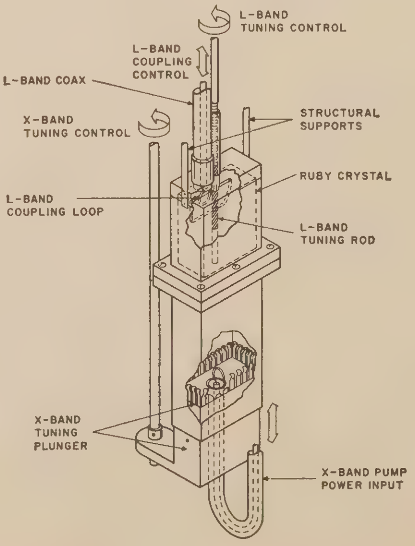

Fig. 3—Tunable maser cavity structure.

The waveguide region not occupied by the rod is beyond cutoff for the signal frequency. Therefore, a contacting plunger located in this region can serve as the tuning element for the X-band pump resonance (which operates in a TE_{107} mode) without affecting the L-band resonance (Fig. 3). The X-band pump power is loop-coupled into the cavity, through the backplate of the X-band tuning plunger, by means of a coaxial line having a bead-supported center conductor. Such a line has an X-band dissipative loss of only a few tenths of a db, has a much smaller cross section compared with waveguide, and the coupling remains reasonably constant over a broad tuning range. The X-band cavity is conveniently tuned from the top by a tuning rod directly connected to the tuning plunger. All low-temperature moving joints (except where electrical contact is required) consist of metal-to-teflon bushings.

Two factors were considered in choosing the 0.086-inch diameter of the L-band tuning rod: 1) the diameter should be as small as possible to minimize its effect on the X-band resonant frequency, and 2) the diameter dimension should yield a high unloaded Q at the L-band signal frequency. Measurements showed that the X-band resonance goes through a cyclical variation of only ±3 mc when the L-band resonance is tuned. The X-band tuning plunger is, as previously stated, in a region beyond cutoff for the L-band mode. Thus, the two resonances are independently tunable.

The coupling to the L-band mode is accomplished by means of a loop that penetrates into a thin slot in the ruby. The loop is oriented in a plane parallel to the broad waveguide dimension to minimize coupling to the X-band pump resonance. The coupling is variable from the top of the Dewar flask by means of a micrometer head that moves the L-band coaxial line in the vertical direction. This varies the penetration of the coupling loop into the maser cavity. Two other micrometer heads located at the top of the Dewar flask are used to tune the L- and X-band cavity resonances. The cavity assembly and the superstructure are shown in Figs. 4 and 5, respectively.

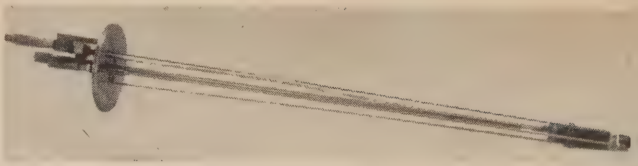

Fig. 4—Maser cavity assembly.

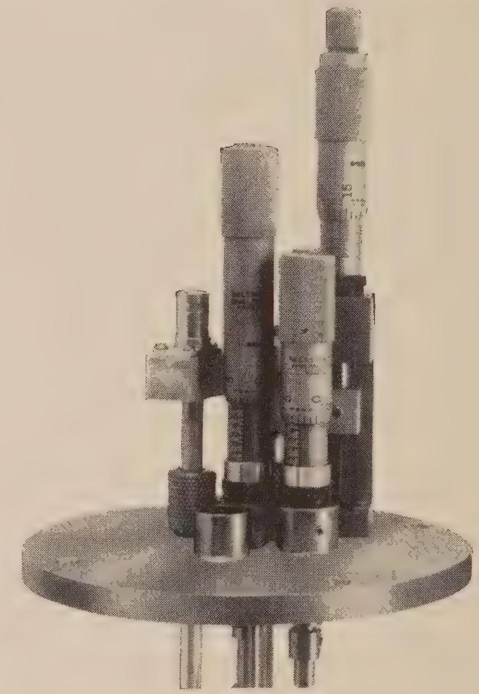

Fig. 5—Cavity superstructure.

IV. MASER PERFORMANCE

The relationship between the pump and signal resonant frequencies of the cavity and the external magnetic field required for maser operation are determined by the inherent quantum-mechanical properties of the paramagnetic crystal. These quantum-mechanical properties (energy levels, RF transition probabilities, and relaxation times) are strongly dependent upon the external magnetic field H and the angular orientation θ between the external magnetic field and the crystal C-axis.

Best L-band maser performance was obtained for an angular orientation θ of 90° at high magnetic fields ($H \approx 2000$ gauss). The energy level diagram for ruby when θ is equal to 90° is shown in Fig. 6. It shows four (low-lying) energy levels, since Cr^{+++} in Al_2O_3 has a spin $S=3/2$. The L-band signal transition and X-band pump transition that were used are between levels 1 and 2, and levels 1 and 3, respectively. The high-field 90° operating point is attractive on theoretical grounds because the calculated signal and pump transition probabilities are high.[10,11] At this operating point, the signal transition probability is maximum when the microwave signal magnetic field is nearly perpendicular to the external magnetic field and parallel to the ruby C-axis. This condition is realized to a fair degree in our design, since the ruby crystal that we utilized had its C-axis oriented in a plane parallel to the broad face of the X-band waveguide, and at 60° to the L-band tuning rod (see Fig. 3), and the signal magnetic field is elliptically shaped for slabline TEM mode employed.

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[10] W. S. Chang and A. E. Siegman, "Characteristics of Ruby for Maser Applications," Electron Devices Laboratory, Stanford University, Stanford, Calif., Tech. Rept. 156-2, Figs. 14 and 15; September 30, 1958. Also, J. Weber, "Masers," *Rev. Mod. Phys.*, vol. 31, pp. 681–710; July, 1959.

[11] E. O. Schulz-DuBois, H. E. D. Scovil, and R. W. DeGrasse, "Use of active material in three-level solid-state masers," *Bell Sys. Tech. J.*, vol. 38, pp. 335–352; March, 1959.

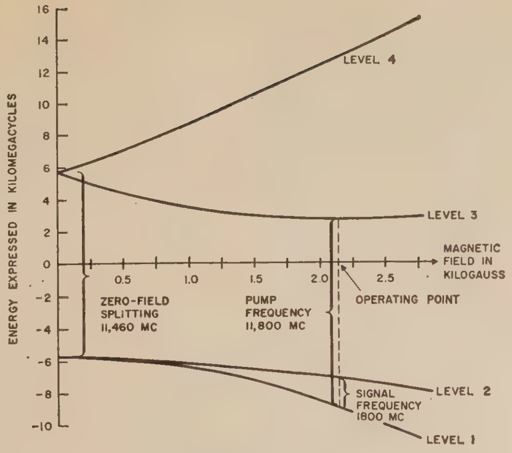

Fig. 6—Energy levels utilized for *L*-band maser.

Measurements of the voltage-gain bandwidth product at high magnetic fields were made at liquid helium bath temperatures of 4.2°K and 1.5°K. The results of these measurements are listed in Table I.

Table I shows that a voltage-gain bandwidth product of 37.5 mc was measured at 1750 mc for a temperature of 1.5°K. Thus, for a half-power bandwidth of 3.75 mc, a gain of 20 db will be obtained. Furthermore, operation was also obtained at an operating temperature of 4.2°K, where a voltage-gain bandwidth product as high as 20 mc was measured.

The gain-bandwidth products measured were used to calculate the effective magnetic Q. For such calculations, Fig. 7 and (3) (Appendix I) can be used, under the condition that the cavity unloaded Q is much greater than the external Q. The effective magnetic Q calculated at 1200 mc (Table I) is 140 and 210 for operation at 1.5°K and 4.2°K, respectively. The magnetic Q is approximately constant over the *L*-band region. There is a deterioration in magnetic Q at the low-frequency end that is probably due to cross-relaxation effects.[12] The pump power that was required varied between 5 and 150 mw for the various measurements.

A four-level experiment was also performed for θ equal to 90° at high magnetic fields. Here, pumping was done between levels 1 and 4, with the signal transition again between levels 1 and 2. Maser operation at a liquid helium bath temperature of 4.2° K was readily obtained at frequencies from 850 to 1750 mc (Table II). However, the measured voltage-gain bandwidth product did not show the expected improvement of greater than 100 per cent (assuming equal relaxation times between all levels) over the three-level arrangement. This may have been due in part to the limited pumping power available from the 20-kmc klystron that was used. Of the 50 mw available from a Raytheon QK306 klystron, only an estimated 10 mw reached the maser cavity. This power level was insufficient to saturate the 20-kmc pump transition, which has a low calculated transition probability.[10]

TABLE I

Summary of *L*-Band Maser Performance (Three-Level Operation)

Liquid Helium Bath Temperature (°K)	Signal Frequency (mc)	Voltage-Gain Bandwidth Product Measured (mc)	Voltage-Gain Bandwidth Product Determined from External Q Measurement (mc)	Pump Frequency (mc)	Magnetic Field (gauss)
4.2	2000	*	*	12,150	2260
4.2	1815	20	22	11,860	2150
4.2	1200	11	13	10,950	1740
4.2	1010	9	12	10,700	1650
4.2	850	*	*	10,460	1510
1.5	1750	37.5	37.5	11,795	2100
1.5	1200	19	20	10,845	1740

* Not measured.

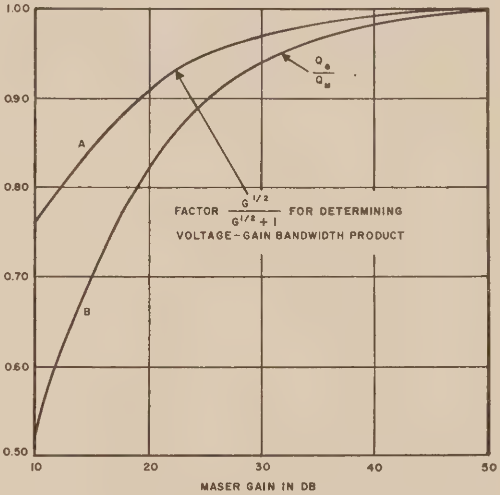

Fig. 7—Relationship of external Q to gain-bandwidth product and magnetic Q for cavity maser [when the cavity unloaded $Q(Q_u)$ is much greater that the external $Q(Q_e)$]. Curve A: Correction factor, due to finite gain, on gain-bandwidth product determined from external-Q measurement. Curve B: Relationship of external Q to magnetic Q as a function of gain.

TABLE II

Summary of *L*-Band Maser Performance (Four-Level Operation)

Liquid Helium Bath Temperature (°K)	Signal Frequency (mc)	Voltage-Gain Bandwidth Product Measured (mc)	Pump Frequency (mc)
4.2	1750	13	21,750
4.2	1005	6	19,180
4.2	855	5	18,420

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[12] N. Bloembergen, S. Shapiro, P. S. Pershan, and J. O. Artman, "Cross-relaxation in spin systems," *Phys. Rev.*, vol. 114, pp. 445–459; April 15, 1959.

For convenient reference, we have plotted the energy levels in ruby in a manner that is particularly suitable for three-level tunable maser operation [Fig. 8(a) and 8(b)]. By plotting pump frequency as a function of magnetic field, with angular orientation θ and signal frequency as parameters, the variation in pump frequency and magnetic field for a given signal tuning range are readily determined. The region of operation used in our maser is indicated by a heavy line in Fig. 8(b).

This form of plotting the energy levels brings out an interesting and useful point, namely, that the ruby crystal can be readily oriented to 90° by varying the crystal orientation until the dc magnetic field required for resonance absorption is maximized. As Fig. 8(b) shows, this alignment technique can be applied to either the pump or signal transition.

V. Low-Loss Circulator

This is a four-port circulator having an insertion loss near 0.3 db and isolations greater than 23 db over a 200-mc frequency range.[9] Fig. 9 shows the circulator. Electrically, it consists of dual 90° non-reciprocal phase-shift sections connected to two hybrids.[13] Our unit used strip-transmission-line hybrids with transitions to a MgMnAl-ferrite-loaded *L*-band waveguide, which was reduced in height to one inch to keep the electromagnet dimensions at a minimum and to reduce the ferrite material requirements.

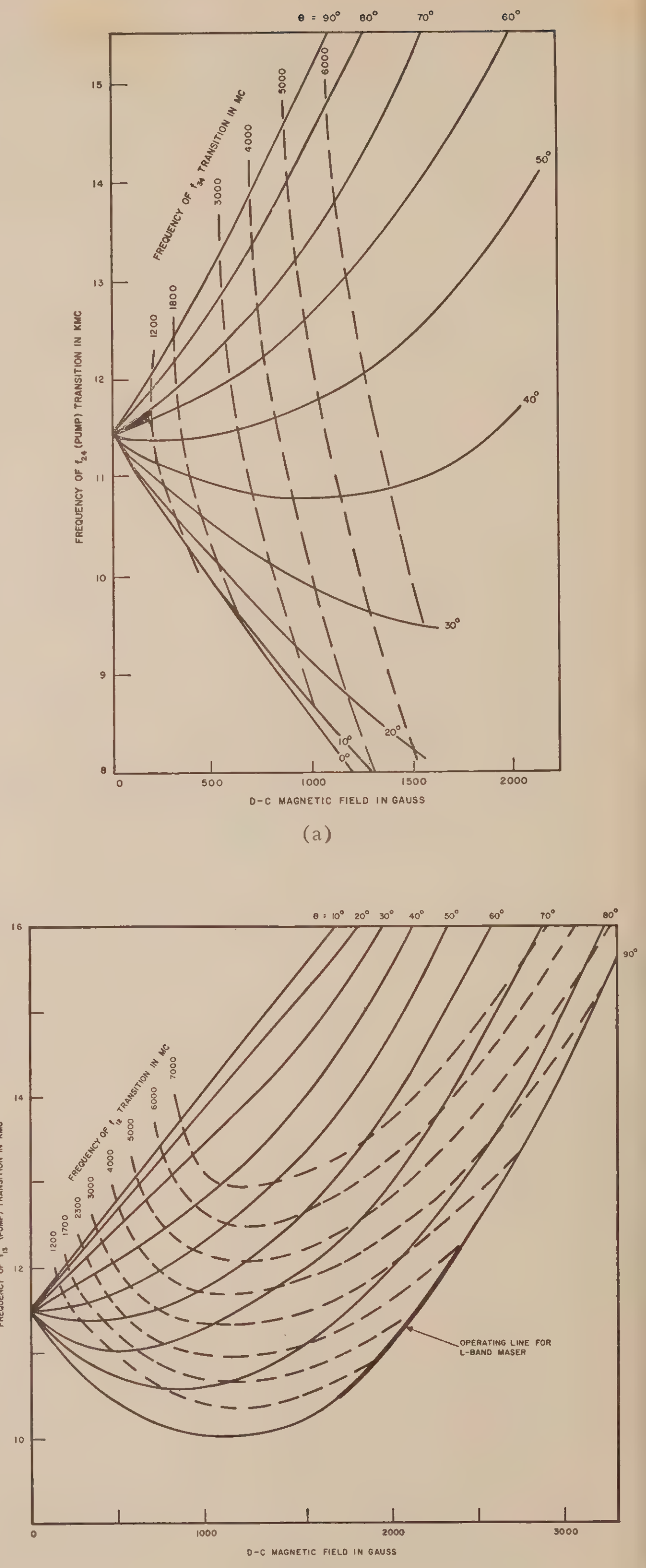
The strip-transmission-line hybrids are shown in detail in Fig. 10, with the top ground plane removed. The ring hybrid is equivalent in its operation to the waveguide folded tee, and the other hybrid is equivalent to the waveguide short-slot hybrid. The use of the strip-transmission-line hybrids results in reasonable physical size.

VI. Package Description and Performance

A. Description of Package

The over-all maser system is housed in two standard relay cabinets (Fig. 11). The smaller cabinet contains the maser cavity structure, stainless-steel Dewar flask, and maser magnet. The larger cabinet contains the associated auxiliary equipment, including (from top to bottom in Fig. 11):

1) oscilloscope to view either the pump or signal frequency cavity resonance and to observe and optimize maser action;
2) current-regulated power supplies to drive circulator and maser electromagnets;



(a)

(b)

Fig. 8—Frequency relationships for three-level ruby maser as a function of magnetic field and angular orientation. (a) Upper three energy levels. (b) Lower three energy levels.

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[13] C. L. Hogan, "Elements of non-reciprocal microwave devices," Proc. IRE, vol. 44, pp. 1345–1368; October, 1956.

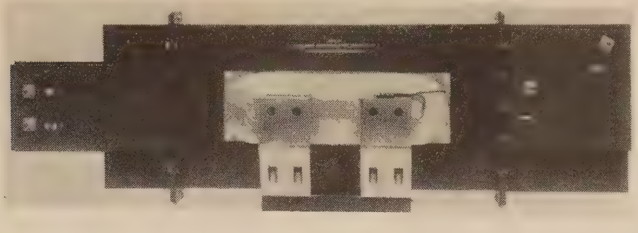
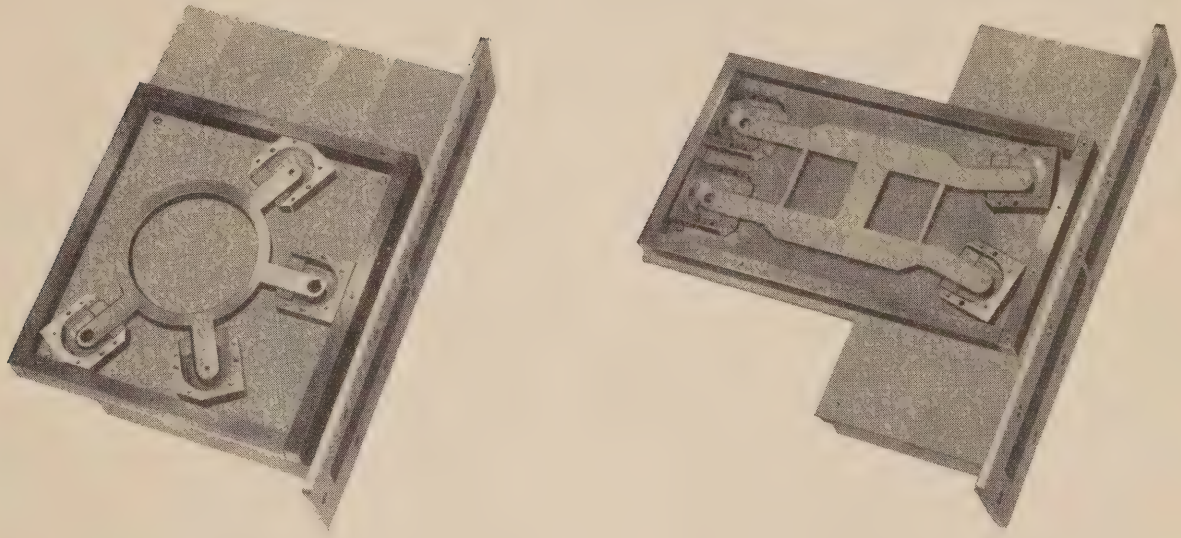


Fig. 9—Low-loss *L*-band circulator.



(a) (b)

Fig. 10—Strip transmission line hybrids used in *L*-band circulator. (a) 180° 3-db hybrid. (b) 90° 3-db hybrid.

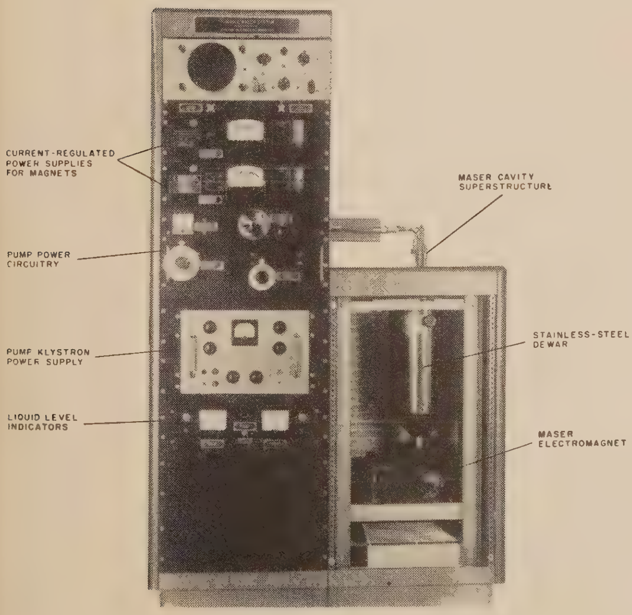

CURRENT-REGULATED POWER SUPPLIES FOR MAGNETS
MASER CAVITY SUPERSTRUCTURE
PUMP POWER CIRCUITRY
STAINLESS-STEEL DEWAR
PUMP KLYSTRON POWER SUPPLY
LIQUID LEVEL INDICATORS
MASER ELECTROMAGNET

Fig. 11—Packaged maser system.

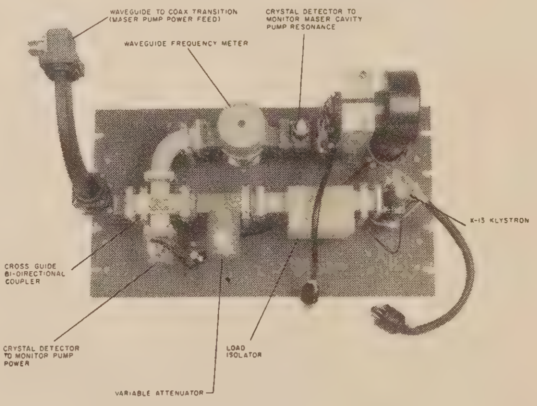

WAVEGUIDE TO COAX TRANSITION (MASER PUMP POWER FEED)
CRYSTAL DETECTOR TO MONITOR MASER CAVITY PUMP RESONANCE
WAVEGUIDE FREQUENCY METER
K-13 KLYSTRON
CROSS GUIDE BI-DIRECTIONAL COUPLER
CRYSTAL DETECTOR TO MONITOR PUMP POWER
LOAD ISOLATOR
VARIABLE ATTENUATOR

Fig. 12—Pump power circuitry.

3) pump power circuitry, including klystron, isolator, variable attenuator, frequency meter, bidirectional coupler, and detectors (shown in detail in Fig. 12);
4) klystron power supply; and
5) liquid level indicators for the refrigerants.

The circulator (which cannot be seen in Fig. 11) is located in the rear of the larger cabinet and is connected to the maser by a low-loss strip transmission line having $1\frac{1}{2}$-inch ground-plane spacing. The input to the maser system consists of $1\frac{5}{8}$-inch coaxial line.

B. General Performance

The maser is easily tuned to any operating frequency over the 200-mc range by adjusting the dc magnetic field, the pump frequency, and the two cavity resonances. All the adjustments necessary for tuning the maser to a specific operating frequency have been calibrated. The signal-frequency cavity-resonance adjustment can be set to any specified frequency within ±2 mc with the calibrated micrometer head. One of the required adjustments, the dc magnetic field, is critical and requires fine tuning. The other two adjustments (pump cavity resonance and pump frequency) are not critical; maser operation can be obtained with the pump cavity resonance and pump frequency detuned as much as 75 mc.

The angular orientation θ of the ruby-loaded maser cavity with respect to the dc magnetic field is not critical. Maser operation has been obtained, without serious degradation in gain-bandwidth product, at angular deviations of several degrees from 90° throughout the tuning range. Consequently, controls for fine-tuning the alignment of the maser cavity were deemed unnecessary. A mechanical feature ensures that the maser cavity structure is correctly oriented when it is inserted into the system.

C. System Noise Temperature

Noise-temperature measurements were made on the maser system using the technique described in Appendix I. The noise generators used for the measurement consisted of two matched loads—one at room temperature and one at liquid nitrogen temperature (Appendix II). A series of measurements, made with the maser operating at high gains, yielded a noise factor of 0.5±0.1 db, which is equivalent to a noise temperature of 35°K.

The main contributing noise sources are:

1) The dissipative losses of the circulator and input coaxial feed lines; these give a noise temperature of approximately 28°K (0.4 db).
2) The second-stage amplifier and other components at the output of the maser having an over-all noise factor of 7.2 db (1230°K). The amplifier consists of a balanced mixer utilizing 1N21EMR crystals and a 30-mc IF amplifier. Its measured noise factor was 6.6 db. With a net maser system gain of 23 db, this contribution is 6.15°K.
3) The maser signal frequency spin temperature, which is calculated to be 1.5°K, for a bath temperature of 4.2°K, assuming equal idler and signal spin-lattice relaxation times.

Thus, good correlation is obtained between the calculated and measured noise temperatures.

D. Maser Saturation Characteristics

A saturation curve that was measured on the maser system is shown in Fig. 13. As can be seen, the gain drops 3 db at a power output of −35 dbm. This yields a dynamic range of 68 db for a post-receiver bandwidth of 1 mc.

Susceptibility of the maser to nearby CW signals is shown in Fig. 14. The power level of the interfering signal, at which the maser gain drops 3 db at its center frequency, is plotted as a function of the frequency of the interfering signal. The shape of the measured response can be closely determined from the frequency response of the active maser cavity. The measurement was made with a three-cavity filter between the maser and the second-stage receiver to ensure that the interference effect measured was primarily due to the maser proper. The filter had a 3-db bandwidth of 15 mc and an insertion loss of 25 db at 15 mc from center frequency.

It is essential that the input level of interfering signals be kept below the microwatt range (Figs. 13 and 14). To insure this, it is desirable to use a preselector cavity and/or passive ferrite limiter that has its limiting

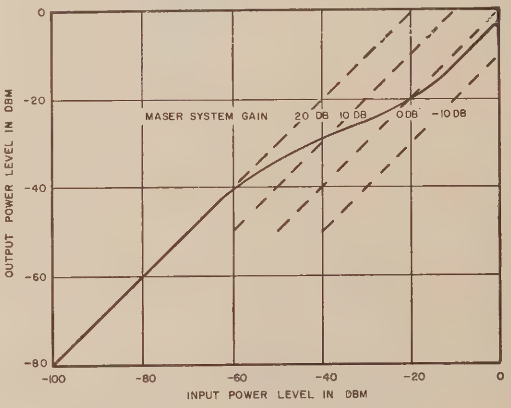


Fig. 13—Maser saturation characteristic due to main signal.

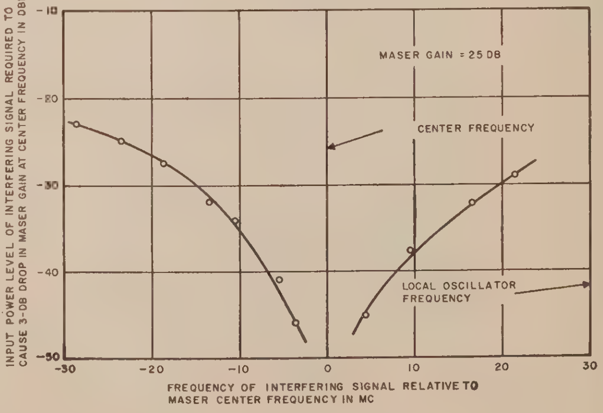


Fig. 14—Maser saturation characteristic due to nearby signals.

threshold at microwatt power levels.[14] These can be placed in the low temperature bath to minimize their noise contribution. The relatively low saturation power level (and relatively long recovery time) of the ruby maser is a result of the relatively long spin-lattice relaxation time of the idler transition, which (for θ equal to 90°) is in the tens of milliseconds at 4.2°K. Future masers will show marked improvements in saturation level and recovery time by using new materials or "impurity-doped" ruby to reduce the idler relaxation time.

To prevent maser saturation effects due to the local oscillator in the second-stage receiver, a balanced mixer should be used. A balanced mixer provides a local-oscillator isolation of 30 db, which, in combination with the circulator isolation and maser cavity selectivity, is more than sufficient to prevent maser saturation effects due to local-oscillator power leakage.

E. Gain Stability

The results of a number of stability measurements at a helium bath temperature of 4.2°K and a maser gain of 22 db yielded a long-term peak-to-peak drift of ± 0.55 db, and a short-term peak-to-peak stability of ± 0.1 to ± 0.2 db over a period of several hours. These figures represent the fluctuations of a complete receiver with the maser front end fed by a standard signal generator. Hence, a portion of the output variation must be ascribed to parts of the measurement setup rather than the maser.

Turbulence in the liquid helium appears to be responsible for some of the short-term gain variations observed in the maser. This effect is reduced by the use of polyfoam loading of the microwave structure. The fluctuations are also significantly reduced by reducing the helium bath temperature below the λ-point (2.2°K), where the liquid helium becomes a superfluid.

The parameter having the greatest detrimental effect on long-term gain stability was found to be the maser magnetic field, which is controlled by a current-regulated power supply. This is evident when it is noted that the regulation must be substantially better than the magnetic line width of the ruby, which is about 1 per cent of the external magnetic field that was used. The electromagnet is designed to permit maser operation over the entire 850 to 2000 mc tuning range of the cavity. Improved stability can be obtained by using a permanent magnet employing an adjustable mechanical shunt or bucking coils for tuning, since a variation in magnetic field of about 6 per cent is needed to cover the 200 mc tuning range of the maser system.

VII. Conclusion

It can be concluded that a cavity maser can be satisfactorily operated over frequency bands greater than one octave. In packaging such a maser together with a circulator for field operational use, the usual 12-inch diameter laboratory magnet and other highly precise supplementary equipment have been eliminated without detrimental effect on gain-bandwidth product, noise figure, and other system parameters. The resulting equipment is reasonably compact and easily operated by semi-skilled personnel.

Appendix I

Techniques for Measuring Maser Gain-Bandwidth Product

The voltage-gain-bandwidth product was determined by two methods. In the first method, gain and half-power bandwidth were measured directly, using the setup shown in Fig. 15. Maser gain is measured by noting the increase in generator output required to maintain a constant output meter reading when the maser is disconnected from the circuit and replaced by a short-circuit at point A of Fig. 15.

In the second method, the external Q of the maser cavity was measured with the pump power and magnetic field turned off. The voltage-gain bandwidth product $G^{1/2}B$ can then be calculated since, for the condition of high gain ($G^{1/2} \gg 1$), it is approximately

$$G^{1/2}B \approx \frac{2f}{Q_e}, \tag{1}$$

where f is the signal frequency and Q_e is the external Q. The more exact expression[15] for $Q_u \gg Q_e$ is

$$G^{1/2}B = \frac{2f}{Q_e}\left[\frac{G^{1/2}}{G^{1/2}+1}\right]. \tag{2}$$

The bracketed term in (2) is the correction factor on the approximation. It is plotted in Fig. 7, and is seen to be less than 10 per cent for gains greater than 20 db.

For comparison with theoretical computations of maser performance, it is desirable to determine Q_m, the magnetic Q, which is a measure of the negative resistance introduced by the paramagnetic maser material.

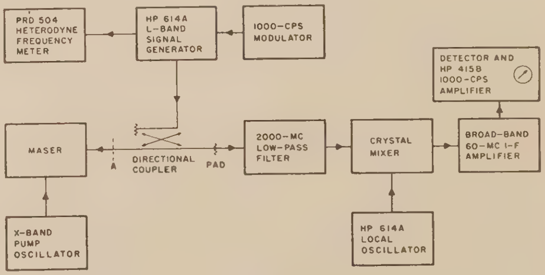

PRD 504 HETERODYNE FREQUENCY METER
HP 614A L-BAND SIGNAL GENERATOR
1000-CPS MODULATOR
DETECTOR AND HP 415B 1000-CPS AMPLIFIER
MASER
A
DIRECTIONAL COUPLER
PAD
2000-MC LOW-PASS FILTER
CRYSTAL MIXER
BROAD-BAND 60-MC I-F AMPLIFIER
X-BAND PUMP OSCILLATOR
HP 614A LOCAL OSCILLATOR

Fig. 15—Measurement setup for maser gain and bandwidth.

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[14] R. W. DeGrasse, "Low-loss gyromagnetic coupling through single crystal garnets," *J. Appl. Phys.*, vol. 30, suppl. 4, pp. 155.S–156.S; April, 1959.

[15] J. O. Artman, "The Solid-State Maser," *Proc. Symp. on Role of Solid-State Phenomena in Electric Circuits*, Polytechnic Inst. of Brooklyn, Brooklyn, N. Y., sec. 3, p. 77; April, 1957.

The magnetic Q is related to Q_e by the expression

$$\frac{Q_e}{Q_m} = \frac{G^{1/2} - 1}{G^{1/2} + 1}, \tag{3}$$

and is plotted in Fig. 7. Obviously, $Q_e \approx Q_m$ for high gains. The correction factor is less than 20 per cent for gains greater than 20 db.

Appendix II

Measurement of System Noise Temperature

Of the several methods used for the measurement of noise temperature,[16] the Y-factor method appeared to be most satisfactory for low noise temperatures. In this method, the output noise power of the receiver, when the input source resistance is at a high temperature T_2, is compared with the output noise power of the receiver when the input source resistance is at a lower temperature T_1. The ratio of these two noise powers is called the Y-factor, which is related to the noise temperature, T_e, by the expression

$$T_e = \frac{T_2 - T_1}{Y - 1} - T_1. \tag{4}$$

The accuracy with which T_e can be determined depends upon how accurately T_1, T_2, and Y are known.

Fig. 16 shows the experimental arrangement used for the noise measurement. The available noise power from the two loads (one maintained at a liquid nitrogen temperature of 77.3°K, and the other at room temperature) is alternately coupled to port 1 of the circulator through a coaxial switch. These noise powers are directed by the circulator into the maser (port 2) and from the maser into a second-stage amplifier consisting of a mixer and an AIL Type 130 Test Receiver. The Y-factor is then accurately determined by using a precision calibrated attenuator that is part of the AIL Type 130 Test Receiver.

It is estimated that the absolute temperature of the two loads can be determined to within ±1°K and that the Y-factor can be measured to within ±0.5 per cent.

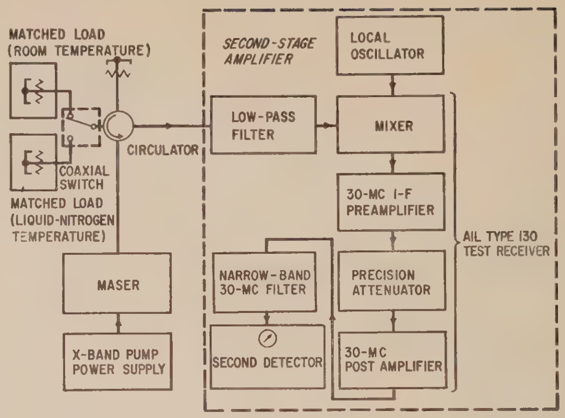

Fig. 16—Measurement setup for maser system noise temperature.

Application of these errors to a variational form of (4) yields a calculated over-all measurement accuracy of better than ±3°K.

In measuring low noise temperatures, the following precautions were taken.

1) The two noise generators (ambient temperature load and the liquid nitrogen load) were well matched.
2) Linearity measurements of the second-stage amplifier were made over a 40-db range. The linearity was found to be within ±0.05 db. In addition, the bandwidth of the second stage was made narrower than that of the first stage, to eliminate bandwidth corrections from the noise-factor measurement.
3) The over-all receiving system was tested for spurious responses. Since broad-band noise sources were used, all spurious responses must be known to reduce the measurement data accurately. All spurious responses were found to be negligible.

Acknowledgment

The advice and aid of C. H. Townes and A. Penzias of Columbia University during the early phases of the project are gratefully acknowledged. The authors also wish to express their gratitude to their co-workers, J. G. Smith and M. Grace, who helped with the packaging and with the measurements.

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[16] M. Wind, "Handbook of Electronic Measurements," Microwave Res. Inst., Polytechnic Inst. of Brooklyn, Brooklyn, N. Y., ch. 13; 1954–1955.

Cadmium Sulfide Field Effect Phototransistor*

R. R. BOCKEMUEHL†

Summary—**The experimental evaluation of cadmium sulfide field effect transistors indicates that, although the material does not compete with germanium for general transistor application, useful power gain was achieved and certain advantages exist for CdS in phototransistor applications. Many unique circuit functions can be performed by the device. The active electronic properties vary greatly with the intensity and wavelength of incident light, and with photoconductivity quenching infrared radiation. Voltage gains greater than 500, mutual transconductances up to 20 μmho and input resistances near 100 megohms have been observed. Electron-hole pairs are generated photoelectrically in the highly pure, single crystal CdS. The holes are virtually immobile and form a space charge when an applied electric field removes the mobile electrons from a region. Modulation of the space charge boundary by application of a potential to one terminal of the device produces modulation of the conductance between two other terminals and signal amplification results. Attempts to correlate the illumination sensitivity of the terminal characteristics with theoretical field effect parameters indicates the carrier distribution in the crystal is complex and varies with illumination wavelength and quenching intensity.**

INTRODUCTION

THE group II–VI compound semiconductors have potential advantages as specialized electronic components with transistor configurations. For example, the utility of photoconductive materials may be extended when fabricated as a transistor. Furthermore, transistor configurations facilitate observation of additional material properties and mechanisms which may extend theoretical understanding of semiconductors. The group II–VI compounds are not expected to compete with elemental or group III–V compounds as general-purpose transistor materials, inasmuch as those studied possess a prohibitively low carrier mobility, or low band gap, or high "intrinsic" carrier concentration.[1] The study of group II–VI transistors is important, however, on the basis of improvement of understanding and utilization of specialized properties, particularly photoelectric properties.

Cadmium sulfide was selected for transistor experimentation because its properties are probably the best known of the II–VI compounds and because it is available in sufficiently pure, single-crystal form.[2] The relatively low mobility of CdS (≈ 200) requires an excessively thin base layer in a junction transistor configuration. However, the unipolar field effect transistor configuration permits practical device dimensions even though mobility is relatively low.

The field effect transistor was first given detailed consideration by Shockley.[3] Modulation of the conductance of a unipolar semiconductor slab is achieved by applying an electric field, perpendicular to the current flow, creating a space charge region which effectively reduces the conducting cross section of the slab. In practice, the transverse field is applied through an intimate, but non-carrier-injecting contact such as a *p-n* junction. Application of the transverse field through an insulating medium does not produce an appreciable space charge in the semiconductor slab because of trapped charges which develop on the slab surface.[3]

Experimental field effect transistors have been fabricated from Ge[4] and Si,[5] and the effect has been observed in InP and GaAs.[6] However, no previous observation of field effect amplification has been reported for any group II–VI compound, nor for any material in which virtually all of the carriers are generated photoelectrically.

FABRICATION

The experimental field effect phototransistors were cut from thin single-crystal plates with a special air-abrasive cutting machine to dimensions of 3 mm × 3 mm square. Thickness was not modified and ranged from 0.15 to 0.5 mm in various units. The thin CdS crystal plates were grown by the vaporization-crystallization method by Boyd and Sihvonen.[2] The placement of the contacts is illustrated in Fig. 1. The contact nomenclature is consistent with that proposed by Shockley.[3] The gate contact is vacuum deposited copper, a few hundredths of a micron thick. The necessary rectifying characteristic is obtained by heating at 400°C for ten minutes in room air. The gate contact is transparent and back resistance is greater than 10^7 ohms. The formation of the rectifying junction is similar to that described by Reynolds, *et al.*;[7] however, the presence of air was found to be necessary during the heating process.

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* Original manuscript received by the IRE, October 22, 1959.

† Res. Labs., General Motors Corp., Warren, Mich.

[1] D. A. Jenny, "The status of transistor research in compound semiconductors," PROC. IRE, vol. 46, pp. 959–968; June, 1958.

[2] D. R. Boyd and Y. T. Sihvonen, "Vaporization-crystallization method for growing CdS single crystals," *J. Appl. Phys.*, vol. 30, pp. 176–179; February, 1959.

[3] W. Shockley, "A unipolar 'field effect' transistor," PROC. IRE, vol. 40, pp. 1365–1376; November, 1952.

[4] G. C. Dacey and I. M. Ross, "Unipolar field effect transistor," PROC. IRE, vol. 41, pp. 970–979; August, 1953.

[5] G. L. Pearson, "High impedance field effect silicon transistors," *Phys. Rev.* vol. 90, p. 336; April, 1953.

[6] A. Herczog, R. R. Haberecht, and A. E. Middleton, "Preparation and properties of aluminum antimonide," *J. Electrochem. Soc.*, vol. 105, p. 535; September, 1958.

[7] D. C. Reynolds, L. C. Greene, and L. L. Antes, "Properties of a cadmium sulfide photo-rectifier," *J. Chem. Phys.*, vol. 25, pp. 1177–1179; December, 1956.

The ohmic source and drain contacts were prepared by electroplating indium from an indium fluoroborate solution after the gate contact heat treatment. All surfaces were cleaned and etched in HCl before contact application. Leads were connected to contacts with silver conducting paint. The units were mounted first on special printed circuit boards, and later in standard transistor headers with transparent cover as shown in Fig. 2.

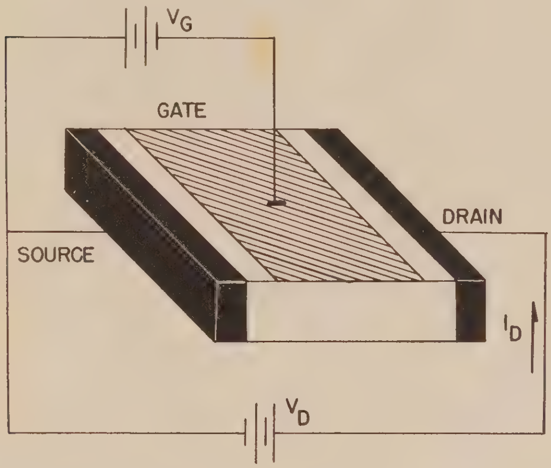

Fig. 1—Field effect phototransistor terminal relationship and common source connection. Source and drain are ohmic; gate is diodic and semitransparent.

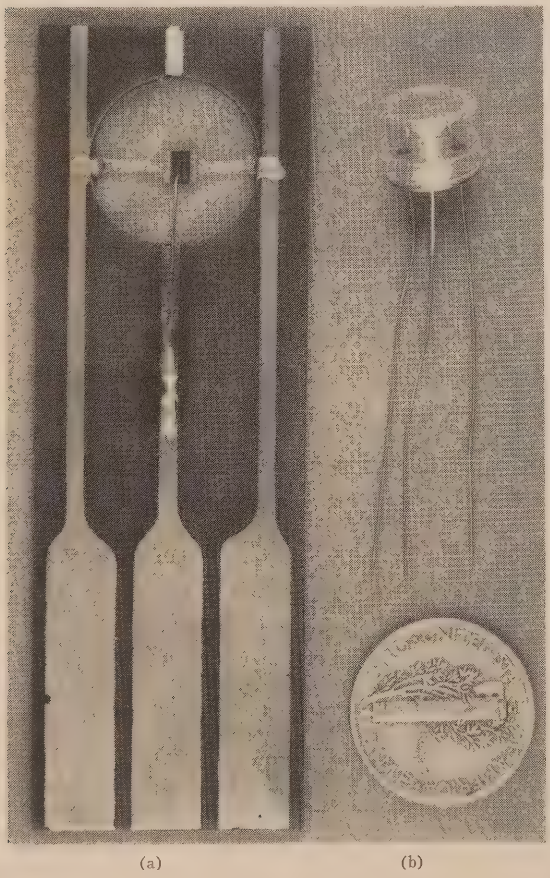
(a) (b)

Fig. 2—Cadmium sulfide field effect phototransistors. (a) Mounted for detailed evaluation. (b) Mounted in transparent transistor header.

Terminal Characteristics

The penetration of the space charge layer into the semiconductor slab, and the resulting decrease in the slab conductance is determined by the magnitude of the reverse bias voltage across the gate junction. Considering the grounded source terminal configuration, Fig. 1, the gate bias voltage is the difference between the potential applied to the gate terminal and the potential in the semiconductor slab. The latter is a function of the drain terminal potential. Thus, the slab conductance is a function of both gate and drain potentials.

The drain terminal voltage-current characteristic at various values of gate voltage (common source) is shown in Fig. 3. A "constant" current region of operation exists when the gate-to-drain potential difference is sufficient to cause the thickness of the space charge layer to approach that of the slab. This bias voltage is designated "pinch-off" voltage V_p. An increase in drain voltage above the V_p value alters the space charge distribution in such a manner to keep the pinch-off current essentially constant. The gate potential determines the value of the pinch-off current; thus an active gate-to-drain mutual transconductance G_m exists. The mutual transconductance, together with the high dynamic output impedance of the device, permits a large voltage gain to be realized. Furthermore, the high gate terminal impedance of the device permits useful current and power gains to be realized.

The terminal characteristics of the field effect phototransistor are dependent on the carrier density within the slab, which is determined by the intensity and wavelength of the incident light excitation. Therefore, these characteristics vary greatly with illumination parameters.

Typical characteristics of a unit when illuminated with an incandescent lamp at an intensity of the order of 200 foot-candles are as follows:

Pinch-off current ($V_g=0$): 200 μa,
Pinch-off voltage: 30 volts,
Mutual transconductance: 20 μmho,
Short circuit current gain: 400,
Open circuit voltage gain: up to 1000,
Output impedance (resistive): up to 50 meghoms,
Input impedance: 20 to 100 megohms depending on load resistance.

A finite gate-to-drain resistance exists which produces feedback resulting in the dependence of input impedance on load resistance and of output impedance on source resistance.

Several experimental phototransistors were operated in a temperature range from −50°F to 150°F with a negligible change in terminal characteristics when illuminated with an incandescent lamp. However, a considerable temperature dependence was observed when illuminated with monochromatic wavelengths greater than 5300 angstroms.

Frequency response varies greatly with operating conditions but extends from dc throughout the audio range.

High-frequency attenuation results from the junction capacity of the gate and from stray capacities in the drain circuit in conjunction with the high dynamic drain impedance.

Photoelectric Characteristics

The pinch-off current of the cadmium sulfide field effect phototransistor is much more sensitive to illumination intensity and wavelength than are the other electrical parameters of the device. The photoconductivity of cadmium sulfide exhibits a sharp peak between 5100 and 5200 Å.[8] The wavelength dependence of pinch-off current of the transistor, and the photocurrent when connected as a two-terminal photoconductor is shown in Fig. 4. Under certain operating conditions, the pinch-off current has been observed to be proportional to the square of the illumination intensity. Sensitivities of the order of 10^{-8} amperes per foot-candle squared have been observed with incandescent illumination.

The pinch-off current is also very sensitive to infrared quenching wavelengths.[9] Certain discrete wavelengths in the 1-micron region, when applied in combination with excitation wavelengths, cause a reduction in the conductivity of cadmium sulfide and produce other effects which sharply reduce the pinch-off current. This wavelength dependence of the pinch-off current and two-terminal photocurrent is shown in Fig. 5. Pinch-off current sensitivities of the order of 1 $\mu a/\mu w/cm^2$ have been observed. The variation of pinch-off current and two-terminal photocurrent with infrared quenching intensity is shown in Fig. 6. The pinch-off current is many times more sensitive to infrared quenching intensity than is the two-terminal photocurrent.

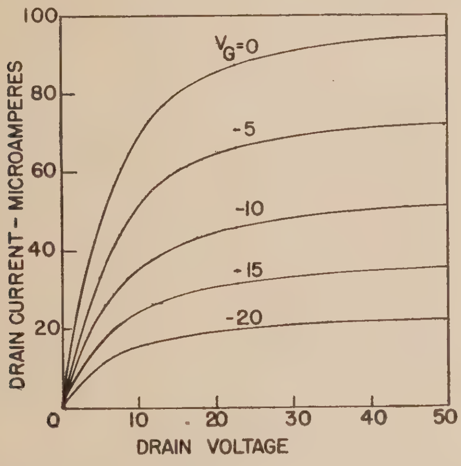

Fig. 3—Typical drain terminal characteristic with common source connection and 200 foot-candle illumination.

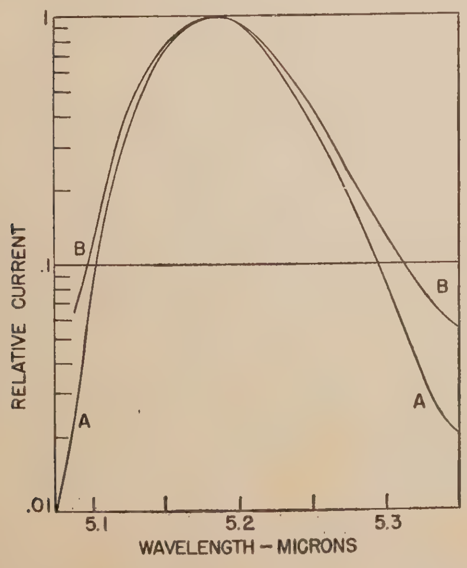

Fig. 4—Pinch-off current A), and two-terminal photocurrent B), as a function of incident wavelength.

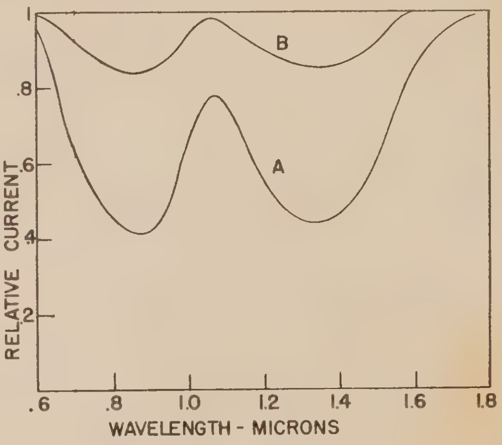

Fig. 5—Infrared quenching vs wavelength with constant excitation illumination from tungsten source; A) pinch-off current, B) two-terminal photocurrent.

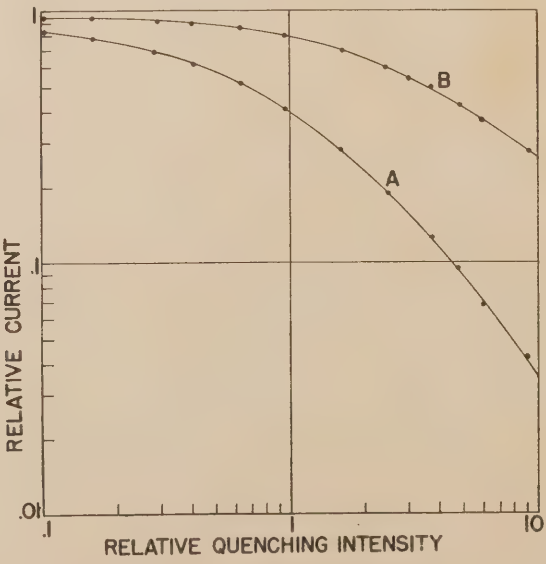

Fig. 6—Infrared quenching vs quenching intensity, A) pinch-off current, B) two-terminal photocurrent. Quenching source: 1200°K black body; excitation source: 2850°K tungsten source with quenching wavelengths filtered out.

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[8] M. Balkanski and R. D. Waldron, "Internal photoeffect and exciton diffusion in cadmium and zinc sulfides," *Phys. Rev.*, vol. 112, pp. 123–125; October 1, 1958.

[9] R. H. Bube, "Infrared quenching and unified description of photoconductivity phenomena in cadmium sulfide and selenide," *Phys. Rev.*, vol. 99, pp. 1105–1116; August, 1955.

FIELD EFFECT PARAMETERS

Field effect theory in a photoconductor differs in detail from that in a doped semiconductor, although generalizations common to both cases can be derived. The parameters used in deriving theoretical relationships are common to both cases but some which are constant in doped semiconductors are variables when photoconductors are considered.

The electrical characteristics of a field effect transistor are dependent on the physical dimensions and the bulk properties of the semiconductor slab. The important dependent and independent parameters are summarized:

V_p = pinch-off potential, volts,
I_p = pinch-off current, amperes,
a = thickness, cm,
c = width, cm,
L = length, cm,
ρ = charge density, coulombs/cm^3,
k = dielectric constant, farads/cm,
μ = carrier mobility, cm^2/volt-second.

The following relationships are based on the gradual approximation defined by Shockley.[3] The potential within the semiconductor slab $V(y)$, the field E_y and the charge density $\rho(y)$ are related by Poisson's equation:

$$-d^2V(y)/dy^2 = dE_y/dy = \rho(y)/k, \tag{1}$$

where (y) is the distance from the gate surface. The induced charge is contained in the space charge layer and an increase in junction bias voltage increases the total space charge by extending the boundary of the space charge layer. The relationship between bias voltage and space charge layer thickness is dependent on the manner in which the space charge is distributed in the material. However, considering a general charge density distribution, the pinch-off potential can be derived from (1) in the following form:

$$V_p = (\rho_0 a^2/2k)[D_v], \tag{2}$$

where $[D_v]$ is a function of the charge distribution, and ρ_0 is the charge density at $y=0$.

Inasmuch as a potential gradient exists in the direction of current flow (x), the potential in the conducting channel and the resulting space charge boundary are both functions of (x), the distance from the source contact. Therefore the current density in the conducting channel is a function of (x). Furthermore, if free carrier distribution in the conducting channel is a function of (y), the conductivity $\sigma(y)$ and the current density J will be a function of (y):

$$J(x, y) = E_x\sigma(y). \tag{3}$$

Integration of (3) over suitable limits yields pinch-off current,

$$I_p = (a^3c\mu\rho_0^2/6kL)[D_1], \tag{4}$$

when the gate-to-source voltage equals zero.

The bulk conductance of the semiconductor slab with no space charge layer is

$$G_0 = (c/L)\int_0^a \sigma(y)dy = (\rho_0 acu/L)[D_g], \tag{5}$$

where $[D_g]$ is another function of carrier distribution.

The mutual transconductance G_m of a field effect transistor with zero bias between gate and source terminals is theoretically equal to the bulk conductance G_0 of the slab.

The portions of (2), (4), (5) which are in parentheses are independent of the charge distribution. The bracketed portions are dependent on charge distribution and are always dimensionless. The distribution functions will generally include the thickness parameter (a). The distribution functions for an exponential charge distribution are derived in the Appendix.

FIELD EFFECT IN A PHOTOCONDUCTOR

The principal differences encountered in consideration of field effects in a photoconductor and in a doped semiconductor result from the differences in the mechanisms which determine the space charge distribution and the carrier distribution in the material. In the analyses made by Shockley[3] and by Warner, *et al.*,[10] semiconductor materials such as Ge and Si were sufficiently activated with donors or acceptors to permit minority carriers to be neglected. The application of an electric field which removes the majority carriers from a region creates a space charge in that region with polarity opposite to that of the removed carriers. The distribution of the charge density in the space charge region is equal to the difference between donor and acceptor density in that region. Furthermore, the distribution of the carrier density in the conducting channel is equal to that of this activation density in the channel.

In an insulating photoconductor, however, electron-hole pairs are generated photoelectrically. In CdS and other n-type photoconductors, free holes produced by pair excitation are captured quickly by imperfection centers.[11] The resulting free hole mobility and lifetime have extremely low values; the holes can be assumed to be immobile in a first-order approximation. Application of an electric field to illuminated CdS, which removes the free electrons from a region, creates a positive space charge in that region in the form of trapped holes.

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[10] R. M. Warner, W. H. Jackson, E. I. Doucette, and H. A. Stone, "A semiconductor current limiter," PROC. IRE, vol. 47, pp. 44–56; January, 1959.

[11] R. H. Bube, "Photoconductivity of the sulfide, selenide, and telluride of zinc or cadmium," PROC. IRE, vol. 12, pp. 1836–1850; December, 1955.

Inasmuch as the space charge and carrier distribution in a doped semiconductor correspond directly to the activation distribution, these values can be evaluated and applied to field effect equations. Furthermore, the distribution functions do not have first-order dependence on external parameters. In a photoconductor, however, the space charge and carrier distribution is an interdependent function of illumination intensity and wavelength, crystal inhomogeneities and electric field. The distribution functions are not only difficult to predict but also vary greatly with external parameters.

The carrier density in a photoconductor is equal to the rate at which the free carriers are generated per unit volume (excitation density) times the mean carrier lifetime in the conduction band before recombining with a hole. The carrier density distribution within the photoconductor slab is dependent on the distribution of the excitation density and on the manner in which the carriers may diffuse or drift from their generation sites. The excitation density at a particular point is proportional to the rate at which light is absorbed at that point. The light intensity distribution is a function of the incident light intensity J_0 and the absorption coefficient α and is related by Lambert's law:

$$J(y) = J_0 \exp(-\alpha y), \tag{6}$$

where (y) is the distance from the illuminated surface. The excitation density $f(y)$ is proportional to the rate of absorption:

$$f(y) = -dJ(y)dy = J_0\alpha \exp(-\alpha y). \tag{7}$$

The absorption coefficient α is a function of wavelength[8] and may vary over a range from 10 to 10^4 cm^{-1}. Thus illumination wavelength is important in determining the excitation density distribution.

Because of their very short lifetime as a carrier and low mobility, the generated holes do not drift an appreciable distance from their point of generation. The drift may not be entirely negligible at illumination wavelengths which yield a very high absorption coefficient, inasmuch as all of the carriers may be generated in an extremely narrow region near the surface. In addition, exciton diffusion lengths in CdS have been reported to be of the order of one cm and exciton production has been found to exceed pair production at certain wavelengths.[8] Excitons may diffuse into unilluminated regions of the crystal and dissociate into electron-hole pairs, thereby influencing charge distribution.

Carrier lifetime is probably nonuniform throughout the crystal, especially in the presence of infrared quenching radiation. Near-infrared radiation in the 0.89- and 1.35-micron regions cause a reduction of the photoconductivity of CdS, as shown in Fig. 5, by effectively reducing the carrier lifetime. A mechanism has been proposed whereby the infrared shifts the population density of certain recombination centers with a resulting increase in recombination rate.[9] The quenching effect is a function of the ratio of quenching intensity to excitation intensity.[9] Most excitation radiation is absorbed in relatively short distances in the crystal, while the absorption of the infrared quenching radiation is very slight. Thus, the ratio of quenching to excitation wavelengths increases with distance (y) from the illuminated surface, and the free carrier lifetime may be expected to decrease with (y), with a corresponding decrease in free electron and trapped hole density. The influence of quenching radiation on the charge distribution may be great and would account for the significantly greater effect of infrared on the pinch-off current than on the two-terminal photocurrent as shown in Figs. 5 and 6. The two-terminal photocurrent is proportional to the bulk conductance of the semiconductor slab. The bulk conductance (5) is proportional to the area under the charge distribution curve, independent of its shape, while the pinch-off voltage and current are extremely sensitive to the distribution characteristic.

All of the factors discussed so far affect the charge distribution in a perfectly homogeneous semiconductor slab. Additional factors exist in a practical device. For example, the carrier lifetime, mobility and infrared effects may be significantly different at the crystal surface than in the interior of the slab, effecting a charge distribution discontinuity near the surface. Furthermore, inasmuch as the gate is formed by heating a copper contact, the copper is diffused a small but finite distance into the crystal. The excitation density, carrier lifetime, mobility, infrared effects and the resulting charge distribution will be different in this "doped" region than in the bulk of the slab.

EXPERIMENTAL CORRELATION

Qualitative correlation of the experimental results with theoretical relationships is possible if an assumption of the charge distribution is made. Quantitative correlation is not possible because of incomplete knowledge relating the many factors which influence the charge distribution. Because of the exponential decrease of light intensity within the crystal, a simple first assumption is that the charge distribution decreases exponentially with distance from the illuminated surface. Then, if the gate surface is illuminated,

$$\rho(y) = \rho_0 \exp(-my), \tag{8}$$

where m is a factor which represents the combined effects of all the mechanisms producing the exponential reduction. With this distribution, the distribution functions in (2), (4), (5) are, as derived in the Appendix,

$$[D_v]_G = (2/m^2a^2)(e^{-ma} + mae^{-ma} - 1), \tag{9}$$

$$[D_I]_G = (3/2m^3a^3)[(2ma + 3)e^{-2ma} - 4e^{-ma} + 1], \tag{10}$$

$$[D_g] = (1/ma)(1 - e^{-ma}). \tag{11}$$

If the surface opposite the gate junction is illuminated, the charge distribution is reversed:

$$\rho(y) = \rho_0 \exp m(y - a), \tag{12}$$

$$[D_v]_0 = (2/m^2a^2)(ma + e^{-ma} - 1), \tag{13}$$

$$[D_I]_0 = (3/2m^3a^3)[(2ma - 3) + 4e^{-ma} - e^{-2ma}]. \tag{14}$$

Inasmuch as the bulk conductance is proportional to the area under the $\rho(y)$ curve, $[D_g]$ is not dependent on which surface is illuminated.

The ratio of the pinch-off current with opposite surface illuminated to that with the gate surface illuminated is equal to the ratio of the corresponding distribution functions:

$$(I_p)_0/(I_p)_G = [D_I]_0/[D_I]_G. \tag{15}$$

Pinch-off current ratios were obtained experimentally at several illumination wavelengths and quenching intensities. When the illumination was changed from the gate side to the opposite side, the illumination intensity was adjusted to yield a common value of bulk conductance. This partially compensates for the reduction of intensity by the semitransparent copper gate. Pinch-off current ratios in the range from 1 to 4 were observed, indicating a variation in the value of (ma) from 0 to 3.1. Thus, a qualitative variation of the charge distribution with both illumination wavelength and quenching intensity is indicated.

The measured value of pinch-off current ratio is subject to error inasmuch as the semitransparent gate reduces the effective incident illumination on only that portion of the surface beneath the gate. When illuminated from the gate side, the relative intensity is greater on the end portions than beneath the gate. However, when illuminated from the opposite side, the incident intensity is uniform over the entire surface. Inasmuch as the portions of the slab outside of the gate region act as degenerative feedback resistances,[4] the resulting feedback ratio will also change with direction of illumination. For this reason, the measured values of the pinch-off current ratios will be slightly lower than the ratios of their distribution functions.

The distribution functions $[D_I]_G$ and $[D_g]$ from (10) and (12), are plotted as a function of (ma) in Fig. 7. The experimentally obtained relationship between pinch-off current and two-terminal photocurrent as a function of infrared quenching intensity, Fig. 6, is qualitatively similar to the theoretical curves, Fig. 7. The similarity between the experimental and theoretical curves indicates that the assumed exponential distribution may not differ greatly from the actual distribution and that the exponent (m) increases with infrared quenching intensity.

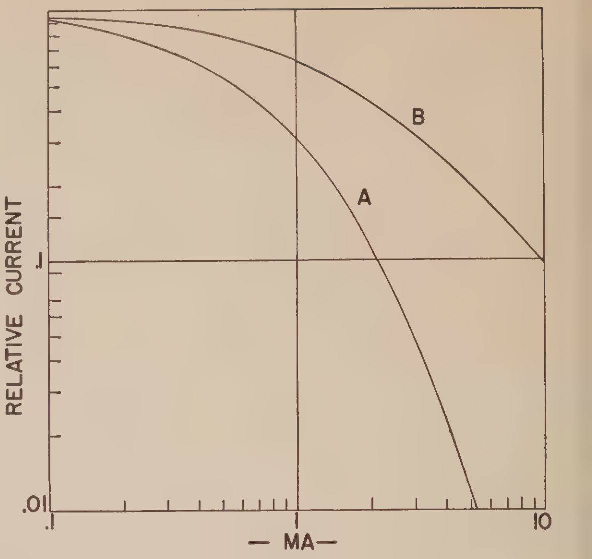

Fig. 7—Theoretical relationship between distribution function and the exponent (ma) with exponential charge distribution, for A) pinch-off current with gate side illuminated, B) two-terminal photocurrent.

Practical Applications

The unique characteristics of field effect phototransistors allow them to perform new and combined circuit functions which are not practicable with conventional circuit elements. Furthermore, they are solid state devices having the small size, high efficiency and ruggedness common to semiconductor components.

Direct connection of the gate-to-drain terminals yields a two-terminal current limiter similar to that described by Warner, *et al.*,[10] but whose limiting current is a function of light intensity. Because of its high ratio of dynamic-to-dc impedance, the device can be applied to conventional two-terminal photoconductor circuits (*i.e.*, bridges and dividers) and produce a considerably greater output voltage change for a given supply voltage than would a simple two-terminal photoconductor. Furthermore, the dependence of pinch-off current on the square of the light intensity has particular advantage in detecting small changes in relatively large light levels.

When connected in a conventional photocell circuit, application of suitable signals to the gate will perform switching and modulating functions. A reference voltage can be applied to the gate terminal which will determine the light intensity required to produce a particular output current for use in illumination control systems. Furthermore, suitable feedback networks between the gate and drain terminals can be used for frequency or temperature compensation, or for arbitrary shaping of the device characteristics.

Inasmuch as the field effect phototransistor has useful power gain, it can be used as an oscillator or as a signal amplifier. Phase shift oscillators employing one phototransistor have been constructed whose amplitude is a function of light intensity or which will oscillate only within a narrow range of incident light intensity. Signal amplifiers have been made which have light dependent gain, and which can be gated on or off with light intensity. Neon lamp relaxation oscillators using the cadmium sulfide transistor in place of the conventional resistor produce a very linear, constant amplitude sawtooth signal whose repetition rate can be varied with gate voltage and light intensity.

Unusual circuit functions can be performed by the device when signal information is contained in both the light modulation and gate voltage. For example, if the device is connected as a marginal oscillator, a discrete output occurs when the incident light intensity is modulated at the oscillator frequency. Furthermore, if the light modulation frequency is the same as that of the gate signal, synchronous phase discrimination results. Other specialized circuit functions can be performed by circuits which include two or more field effect phototransistors or by combining with other active circuit elements. The combination of this amplifying photoconductive device with electroluminescent devices may extend the utility of photoelectric circuits.[12]

PRACTICAL LIMITATIONS

The CdS field effect transistor does not compete with conventional junction transistors or vacuum tubes for general amplification applications. The major difficulties encountered in design of practical circuits using the device result from the relatively low mutual transconductance and high output impedance.

The mutual transconductance with zero gate voltage is approximately equal to the bulk conductance of the semiconductor slab, (5), and is a function of the carrier charge density, mobility and slab dimensions. Carrier density is the only parameter sufficiently flexible to permit a significant increase in transconductance. Increasing carrier density by a factor of 10 will increase G_m by that factor but will also increase pinch-off voltage by 10, pinch-off current by 100 and quiescent power dissipation by 1000. This results in impractical values for pinch-off current and voltage, and the power dissipation and electric field in the semiconductor slab may reach destructive limits of the material. Thus, G_m is limited to values of the order of 10 μmho in a CdS field effect transistor.

Both the output and input resistances of the CdS transistor are higher than are normally encountered with junction transistors and vacuum tubes. Efficient coupling to other active circuit elements is difficult and its advantageous use as an amplifying element is limited to low-frequency applications requiring high impedance levels (*i.e.*, photomultiplier or ion chamber signal amplification).

Improvement of the practical amplification characteristics can be achieved by increasing the carrier mobility of the slab material. This requires selection of a different material and would ultimately lead to an elemental or a group III-V compound semiconductor. However, CdS is very likely the best material for phototransistor application.

APPENDIX

A more general mathematical formulation is required to derive field effect equations for exponential charge distribution than is necessary for uniform[3] or linear graded[10] distributions. If the charge distribution is known, a relationship $V_g=f(h)$ can be derived from the gate potential as a function of the thickness of the space charge layer. Subsequent operations are simplified if the relation $h=g(V_g)$ can be found. This can be done for the uniform or linear graded case but is not possible for the exponential charge distribution case.

With exponential charge distribution of the form,

$$\rho(y) = \rho_0 \exp(-my), \tag{16}$$

the field in the y direction is assumed to be zero in the conducting channel ($h \leq y \leq a$) using Shockley's gradual approximation.[3]

$$\begin{aligned} E_y &= (I/K) \int \rho(y)dy = 0 \quad \text{at} \quad y = h \\ &= -(\rho_0/mk)(e^{-my} - e^{-mh}). \end{aligned} \tag{17}$$

The maximum field E_p required to pinch-off the conducting channel ($h=a$) exists at $y=0$:

$$E_p = (-\rho_0/mk)(1 - e^{-ma}). \tag{18}$$

The potential in the space charge region $V(y)$ is equal to the gate voltage V_g at $y=0$:

$$\begin{aligned} V(y) &= -\int E_y dy = V_g \quad \text{at} \quad y = 0 \\ &= (\rho_0/m^2K)(1 - e^{my} - mye^{-mh}) + V_g. \end{aligned} \tag{19}$$

With finite channel current, the potential in the conducting channel is a function of x, the distance from the source. The potential $V(x)$ cannot be derived directly for the exponential case but can be solved for $V(h)$ where h is a function of x:

$$\begin{aligned} V(h) &= V(y) \quad \text{at} \quad y = h \\ &= (\rho_0/m^2K)(1 - e^{-mh} - mhe^{-mh}) + V_g. \end{aligned} \tag{20}$$

With a gate-to-source potential V_g, a finite space charge layer thickness H_s will exist at $x=0$. Furthermore, $V(h)=0$ at $x=0$, so from (20),

$$V_g = (\rho_0/m^2K)(e^{-mH_s} + mH_s e^{-mH_s} - 1). \tag{21}$$

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[12] S. K. Ghandhi, "Photoelectronic circuit applications," PROC. IRE, vol. 47, pp. 4–11; January, 1959.

The space charge layer thickness H_D at the drain end of the channel ($x=L$) is related to the gate voltage and the drain voltage V_D:

$$V_g - V_D = (-\rho_0/m^2K)(1 - e^{-mH_D} - mH_De^{-mH_D}). \quad (22)$$

The potential V_p required to pinch off the conducting channel is equal to $V_g - V_D$ at $H_D=a$:

$$V_p = (\rho_0/m^2K)(1 - e^{-ma} - mae^{-ma}). \quad (23)$$

The current in the conducting channel is constant at all values of x. The charge density represented by the free electrons in the conducting channel is assumed to be equal to $-\rho(y)$ in that region. The immobile holes generated in that region do not contribute to the channel conductivity. Additional free electrons forced into the conducting channel by the transverse field are rapidly distributed throughout the conducting system of the circuit and do not contribute significantly to the steady state channel current. Although the channel current is not a function of x, the current density J in the channel is a function of both x and y because of its dependence on $h(x)$ and $\rho(y)$:

$$J(x, y) = - E_x\mu\rho(y). \quad (24)$$

The channel current is obtained by integrating (24) and inserting the slab width c and the relationship $E_x = -dV(x)/dx$:

$$\begin{aligned} I &= c\mu(dV/dx)\int_h^a \rho(y)dy \\ &= (c\mu\rho_0/m)(e^{-mh} - e^{-ma})(dV/dx). \quad (25) \end{aligned}$$

Then, by substituting $dV(x)/dx = (dV/dh)(dh/dx)$ where $(dV/dh) = (\rho_0k/h)\exp(-mh)$ from (20),

$$I\int_0^L dx = \frac{c\mu\rho_0{}^2}{mK}\int_{H^s}^{H_D}(he^{-2mh} - he^{-m(a+h)})dh. \quad (26)$$

At pinch-off, $H_D=a$ and with zero gate voltage, $H_S=0$. The current I_p existing with these conditions is

$$I_p = (c\mu\rho_0{}^2/4m^3KL)\left[(2ma + 3)e^{-2ma} - 4e^{-ma} + 1\right]. \quad (27)$$

The mutual transconductance from gate to drain is

$$\begin{aligned} G_m = (\partial\,|\,/\partial V_g) &= (\partial\,|\,/\partial H_S)(\partial V_g/\partial H_S)^{-1} \\ &\quad + (\partial\,|\,/\partial H_D)(\partial V_g/\partial H_D)^{-1}. \quad (28) \end{aligned}$$

The partial derivatives are obtained from (21), (22), (26):

$$G_m = (c\mu\rho_0/mL)(e^{-mH_S} - e^{-mH_D}). \quad (29)$$

The bulk conductance of the slab is

$$G_0 = (\mu c/L)\int_0^a \rho(y)dy = (c\mu\rho_0/mL)(1 - e^{-ma}). \quad (30)$$

Note that with zero gate voltage, ($H_S=0$), and with $V_D = V_p$, ($H_D=a$), then $G_m = G_0$.

ACKNOWLEDGMENT

The cadmium sulfide field effect transistor program was initiated and coordinated by E. F. Weller. Additional appreciation is extended to Y. T. Sihvonen who supplied the CdS crystals and prepared the contacts on the first successful units, to J. W. Bergstrom and F. D. Bosco who further developed fabrication techniques, and to A. J. Gioia who assisted in parameter evaluation.

The Optimum Formula for the Gain of a Flow Graph or a Simple Derivation of Coates' Formula*

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Summary—Starting from the definition of a determinant and using a few of its elementary properties, this paper gives an independent derivation of the optimum formula for the gain of a flow graph. Thus, a simpler path is shown to Coates' important result. This paper is self-contained, so that no previous knowledge of flow graphs is required. For motivation, the reader is referred to some well known papers and books.

I. INTRODUCTION

MASON'S signal flow graphs[1,2] constitute a very useful tool for analysis of engineering problems, linear problems especially. The reason for their popularity and usefulness is that they display in a very intuitive manner the causal relationships between the several variables of the system under study. Many people have successfully used flow graph ideas in various fields.[1–9] Therefore, the publication of Mason's second paper[2] giving a systematic method for writing down almost by inspection the gain of a linear system was an important addition to the flow graph literature. Presently the state has been reached where a great many engineering schools include signal flow graphs in one of their senior courses.[5]

More recently, C. L. Coates[3] has shown that Mason's general gain formula is not the simplest expansion and has given a rigorous and lucid derivation of a new gain formula that is optimum in the sense that, *in general*, 1) no cancellations can occur between common factors of the numerator and denominator, and, 2) no cancellation can occur among the terms of the algebraic sums of the numerator and of the denominator.

The purpose of this paper is to present an independent derivation of Coates' formula. The author's hope is that this derivation is so simple that even seniors can grasp it![10] The only required background is the definition of a determinant. For the reader's convenience, this definition and the properties of determinants used in the derivation are listed in the Appendix.

For further background, motivation and examples, the reader is referred to the literature.[1–3,5] The present paper is self-contained in that it can be read independently of Mason's and Coates' papers.[1–3]

A word about the organization of the paper: There is a difference between Mason's and Coates' procedure for drawing the flow graph of a linear system. The difference, however, is very slight. The first five sections constitute an independent derivation of Coates' formula; they use exclusively Coates' procedure for associating a flow graph to a system of equations. Section VII discusses the difference between Mason's signal-flow graphs and Coates' flow graphs; it shows how, given one of them, the other may easily be obtained.

II. THE SET OF EQUATIONS AND ITS ASSOCIATED FLOW GRAPH

Our purpose is to solve by topological methods the set of linear algebraic equations

$$\sum_{j=1}^{n} a_{kj}x_j - b_k = 0 \qquad (k = 1, 2, \cdots, n). \qquad (1)$$

To this set of equations we shall associate a *flow graph* which is defined as follows:

> Definition 1—A *flow graph* is a set of weighted oriented branches which connect at nodes. That is, each branch has a positive direction and a weight, the branch gain.

The flow graph associated with (1) has n nodes and one source node. The case $n=2$ is illustrated in Fig. 1. The process of associating a flow graph to a set of equations is as follows:

1) To the source node is associated an input variable that is taken to be unity.
2) To each of the other nodes is associated one of the variables $x_1, x_2, \cdots, x_n$ of the set.

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* Original manuscript received by the IRE, August 10, 1959; revised manuscript received, December 7, 1959. This research was supported by the U. S. Air Force, through the Air Force Office of Scientific Research, Air Research and Development Command.

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[10] Some school will insist that the word "seniors" be replaced by "sophomores." More power to them!

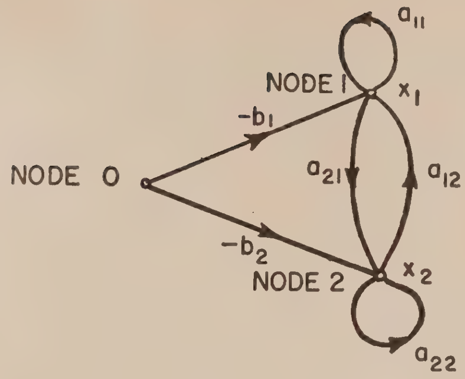

Fig. 1—Flow graph for the case of 2 equations with 2 unknowns.

3) Each node is labelled by one of the integers from 1 to n such that the node labelled k is associated with x_k. The source node is labelled 0.
4) If $a_{jk} \neq 0$, there is a branch directed from node k to node j with gain a_{jk}.
5) If $b_k \neq 0$, there is a branch connecting the source node 0 to node k. This branch is directed from 0 to k and its branch gain is $-b_k$.

This process describes how one goes from the equations to the graph. The reverse process, to obtain the equations from the graph, is very simple.

Consider Fig. 1 and concentrate on node 1. In order to write the equation associated with node 1, first consider all the branches coming into node 1; they are a_{11}, a_{12} and $-b_1$. The equation is obtained by equating to zero the sum of the products of their branch gains times the variables these branches originate from, viz:

$$a_{11} x_1 + a_{12} x_2 - b_1 \cdot 1 = 0.$$

Physically, we may think of these nodes as high gain operational amplifiers whose feedback loop is open. Because, in that case, if the output voltage is in the linear range of the amplifier, the sum of the currents into the input node must be very nearly zero.

At this stage an important point should be brought up. It is clear that to every set of equations such as (1) corresponds a flow graph and conversely. If, however, the order in which the equations appear in (1) is changed, the corresponding flow graph changes in a nontrivial manner. For example, to the set of equations

$$\begin{cases} \qquad \alpha x_2 + \beta x_3 = 0 \\ \gamma x_1 \qquad + \delta x_3 = b_1 \\ \epsilon x_1 + \eta x_2 \qquad = b_2 \end{cases}$$

corresponds the flow graph of Fig. 2.

Rearranging them as follows, we get a new set of equations

$$\begin{cases} \gamma x_1 \qquad + \delta x_3 = b_1 \\ \epsilon x_1 + \eta x_2 \qquad = b_2 \\ \qquad \alpha x_2 + \beta x_3 = 0 \end{cases}$$

and the flow graph of Fig. 3.

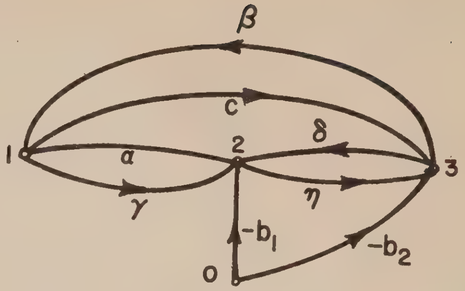

Fig. 2—Flow graph of the system (2).

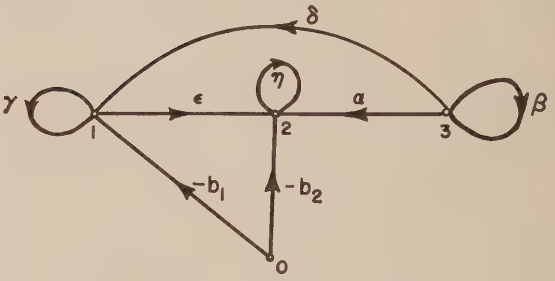

Fig. 3—Flow graph of the system (3).

Thus, once a system of linear homogeneous algebraic equations, such as (1), has been ordered in a fixed way, there is a one-to-one correspondence between the equations and the flow graph.

III. Algebraic Solution of (1)

If the matrix of the coefficients of the x_j's in (1) is nonsingular, the solution is given by

$$x_l = \frac{\sum_{k=1}^{n} \Delta_{kl} b_k}{\Delta} \qquad (l = 1, 2, \cdots, n) \qquad (2)$$

where

Δ is the determinant of the coefficient matrix (a_{ij}).
Δ_{kl} is the cofactor of the element of the kth row and lth column.

In the following we shall devise a topological method for evaluating Δ and products of the form $b_k \Delta_{kl}$.

IV. Topological Evaluation of Δ

In order to evaluate Δ by topological means, we require a few topological ideas; hence we define:

G to be the flow graph of the system (1), where the equations are taken in the order in which they appear;
G_0 to be the flow graph obtained from G by deleting the source node 0.

Definition 2—*A connection* of the flow graph G is a subgraph of G such that

1) each node of G is included,

2) each node has only one branch terminating to it and one branch originating from it.

Definition 3—*A directed loop* is a connected subgraph whose branches $b_1, b_2, \cdots, b_l$ can be ordered in such a way that

1) The tip of b_k is the origin of b_{k+1} $(k=1, 2, \cdots, l-1)$.
2) The origin of b_1 is the tip of b_l.
3) Each node along the directed loop is encountered only once.

Thus, a directed loop is precisely what is meant by a loop in the ordinary language. Fig. 4 illustrates the concept. Fig. 5(a) shows a flow graph G and Fig. 5(b) its five connections. It is clear that a connection is either a directed loop or a collection of nontouching directed loops (they are nontouching because of 2) in definition 2).

In addition, we shall need this definition:

Definition 4—*The connection-gain* of a connection of G is the product of the branch gains of the branches of that connection. It is denoted by $C(G)$.

The first link between the determinant Δ and the flow graph G is obtained by referring to the definition of a determinant:[4]

$$\Delta = \sum_P (\text{sgn } P) a_{1i_1} a_{2i_2} \cdots a_{ni_n} \qquad (3)$$

where the summation is taken over all the $n!$ permutations $P=(i_1, i_2, \cdots, i_n)$ of the integers, $1, 2, \cdots, n$ and (sgn P) is $+1$ or -1 depending on whether the permutation P is even or odd.[11]

Lemma 1: A product appears in (3) if and only if it is a connection-gain $C(G_0)$ of the flow graph G_0.

Proof: Recall that G_0 is the graph G with the source node 0 deleted. Consider a particular product $\prod$ in the sum (3). Let $\prod'$ be the set of all branches whose gain appear in the product $\prod$. Since $\prod$ is a product of factors a_{ki_k}, with k running from 1 to n, there is one and only one branch of $\prod'$ that terminates at each of the n nodes of G_0. Since $i_1, i_2, \cdots, i_n$ is a permutation of $1, 2, \cdots, n$, there is one and only one branch of $\prod'$ originating from each node of G_0. Hence $\prod'$ is a connection of G_0.

Conversely, given an arbitrary connection of G_0, since it contains by definition one branch terminating in each of the nodes of G_0 and one branch leaving each one of the same nodes, then its connection-gain can be written as

$$a_{1j_1} a_{2i_2} \cdots a_{ni_n}$$

where $i_1, i_2 \cdots, i_n$ is a permutation of the numbers $1, 2, \cdots, n$. Hence, it will appear as one of the products of the expansion (3).

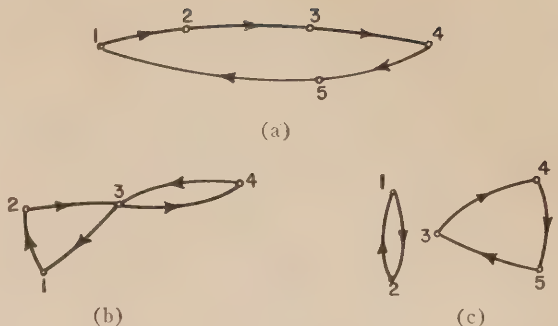

Fig. 4—(a) Example of a directed loop. (b) This is not a directed loop; when traversing the loop in the positive direction, node 3 is encountered more than once. (c) This is not a directed loop because it is not a connected subgraph.

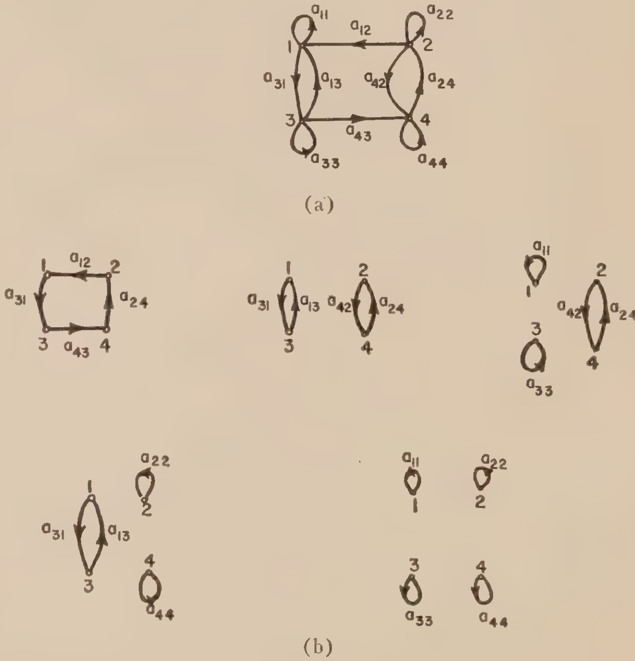

Fig. 5—(a) Flow graph associated with the matrix A. (b) The five connections of the flow graph shown in Fig. 5(a).

Thus by simply listing all the connections of G_0, as is done on Fig. 5, one obtains all the terms of the sum (3). The question of the signs remains. First let us make two rather obvious statements:

Statement 1—If, in a determinant, such as the one of the matrix A, any two rows are interchanged *and* the corresponding columns are also interchanged, the value of the determinant is not affected. (See Appendix, Property 3.)

Statement 2—Consider the system of equations (1) and its associated flow graph G. Suppose any two equations, say the ith and the kth, are interchanged and also the two variables located in the corresponding columns (*i.e.*, x_i and x_k): then to the resulting set of equations (1') corresponds a new flow graph G'. A little thought will show that G and G' are identical except for an interchange of the labels of the ith and kth node.

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[11] The Appendix lists the three properties of determinants that will be used later.

The method required for specifying the sign of each term of (3) is obtained by the following reasoning:

Consider again a particular product $\prod$ of the sum (3) and its associated connection $\prod'$ of the graph G_0. $\prod'$ is a collection of directed loops; for simplicity let us assume that $\prod'$ consists of three nontouching directed loops having respectively n_1, n_2, n_3 nodes. Clearly, $n_1+n_2+n_3=n$, since all nodes of G_0 are included.

As a consequence of Statements 1 and 2 we can, without affecting any of the terms of the determinant expansion (3), relabel the nodes of $\prod'$ so that along the first directed loop of $\prod'$ as it is traversed in the positive direction one traverses the nodes $1, 2, \cdots, n_1$ in that order; and similarly for the other two directed loops. The branch gain product of the first directed loop is then

$$a_{1n_1}a_{21}a_{32}\cdots a_{n_1,n_1-1}.$$

Note that the factors of this product are ordered so that their row subscripts occur in their natural order as required by (3). Hence, the sign assigned to $\prod$ is that assigned to the permutation, defined by the column subscripts:

$$n_1, 1, 2, 3, \cdots, n_1-1; n_1+n_2, n_1+1, \cdots (n_1+n_2-1);$$
$$(n_1+n_2+n_3), (n_1+n_2+1), \cdots (n_1+n_2+n_3-1).$$

To rearrange this permutation in the natural order, $(n_1-1)+(n_2-1)+(n_3-1)=n-3$ interchanges between adjacent symbols are required. Hence, the sign of the permutation is $(-1)^{n-3}=(-1)^n(-1)^{+3}$. Note that there are three directed loops in the product $\prod$. It is clear that if the connection $\prod'$ had L directed loops the sign would have been $(-1)^{n+L}$.

Thus, we obtain the general

Theorem 1: The determinant Δ of the system (1) can be evaluated from its flow graph G by the formula

$$\Delta = (-1)^n \sum_p (-1)^{L_p} C(G_0)_p \tag{4}$$

where

L_p is the number of directed loops in the pth connection.

$C(G_0)_p$ is the connection gain of the pth connection.

G_0 is the flow graph G with the source node 0 deleted.

The summation of the connection gains $C(G_0)$ is taken over all connections of G_0.

Example: The determinant of the matrix associated with the graph of Fig. 5. From the graph G of Fig. 5, we obtain the matrix

$$A = \begin{bmatrix} a_{11} & a_{12} & a_{13} & 0 \\ 0 & a_{22} & 0 & a_{24} \\ a_{31} & 0 & a_{33} & 0 \\ 0 & a_{42} & a_{43} & a_{44} \end{bmatrix}.$$

From the five connections of G shown on the figure,

$$\det A = -a_{12}a_{24}a_{43}a_{31} + a_{13}a_{31}a_{42}a_{24} - a_{11}a_{33}a_{42}a_{24}$$
$$- a_{22}a_{44}a_{13}a_{31} + a_{11}a_{22}a_{33}a_{44}.$$

This expansion can also be obtained by Mason's method, but his general formula will give 25 terms which will eventually reduce to the five listed above.

V. EVALUATION OF THE NUMERATOR OF (2)

The numerator of (2) is a sum of terms all having the same form. Consider one of them in particular; say, $\Delta_{kl}b_k$. In other words, we are going to evaluate the numerator of (2) assuming that there is only one branch, with gain $-b_k$, connecting the source node 0 to the rest of the graph, as shown on Fig. 6(a). Since we know how to evaluate an $n\times n$ determinant by topological means, let us note that $\Delta_{kl}b_k$ is equal to the determinant obtained by replacing the lth column of Δ by a column of zero except for the element of the kth row, which is b_k.

$$\left|\begin{array}{c} 0 \\ 0 \\ b_k \\ 0 \\ \vdots \\ 0 \\ 0 \end{array}\right| \begin{array}{l} \\ \\ \leftarrow k\text{th row} \\ \\ \\ \\ \\ \end{array}$$

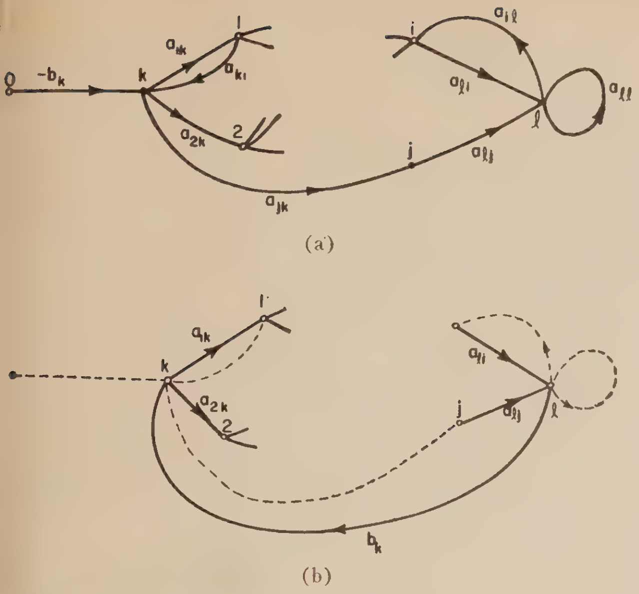
$$\uparrow l\text{th column}$$

This determinant will not change if all the elements of the kth row, with the single exception of b_k, are replaced by zero. The result is the determinant Δ'.

$$\Delta' = \left|\begin{array}{ccccc} & & 0 & & \\ & & \vdots & & \\ & & 0 & & \\ 0\ 0\cdots & & 0\ b_k & 0\cdots 0 \\ & & \vdots & & \\ & & 0 & & \\ & & 0 & & \end{array}\right| \leftarrow k\text{th row}$$

$$\uparrow l\text{th column}$$

In order to evaluate Δ' by topological means, let us note that the flow graph G' associated with Δ' is obtained from G_0 by: 1) deleting all branches leaving node l (the node with which the variable x_l, being sought, is associated); 2) deleting all branches coming into node k; and 3) adding the branch b_k oriented from node l to node k. This operation is illustrated on Figs. 6(a) and



(a)

(b)

Fig. 6—(a) Flow graph G. (b) Flow graph G' obtained from G by deleting all branches leaving node l, deleting all branches coming into node k and adding branch b_k oriented from node l to node k.

6(b). From (4),

$$b_k\Delta_{kl} = \Delta' = (-1)^n \sum_{\tau} (-1)^{L_\tau} C(G')_\tau$$

where

$C(G')_\tau$ is the connection gain of the τth connection of G'.

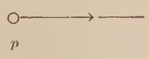
L_τ is the number of directed loops of the τth connection.

The summation is taken over all connections of G'.

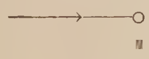
In order to interpret this result in terms of the graph G, let us define as follows:

Definition 5—*A one-connection* from p to q of a flow graph G is a subgraph of G which includes all the nodes of G, and such that

1) no branch terminates at p and only one branch of the subgraph originates from p, thus:



2) no branch originates from q and only one branch of the subgraph terminates at q, thus:



3) all other included nodes have exactly one incoming and one outgoing branch.

An example of a set of one-connections is shown on Figs. 7 and 8. It is apparent from Fig. 8 that, in general, a one-connection is a forward path together with some directed loops.

Consider Fig. 6(b). Each one of the connections of G' includes the branch b_k because it is the only branch that leaves the lth node. In each one of these connections let us remove the origin of branch b_k from node l and place it at the source node 0 where it was originally in graph G. Finally, let us change the branch gain from b_k to $-b_k$. In each case the resulting configuration is a *one-connection* from 0 to l of flow graph G. Since by displacing the branch b_k one directed loop has been "opened," the number of directed loops in the one-connections of G is one less than that of the original connections of G'; this will result in a change of sign which will cancel the one caused by the change of sign of the branch gain b_k. Consequently,

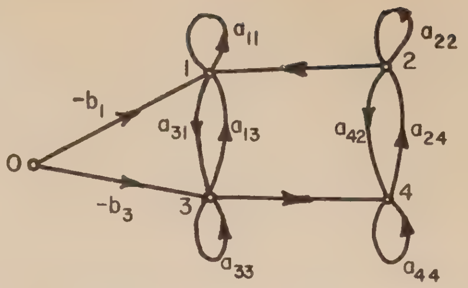


Fig. 7—Flow graph associated with the set of equations (6).

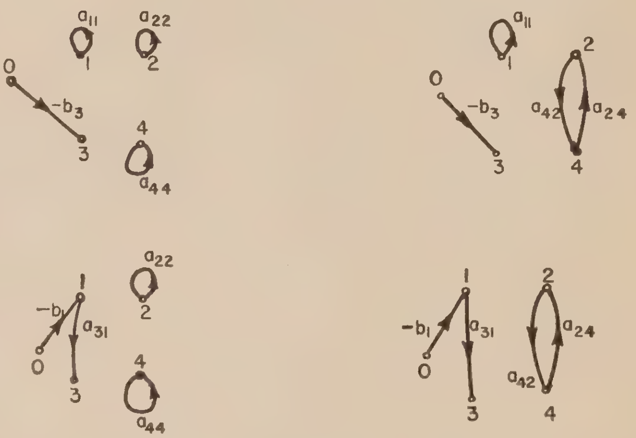


Fig. 8—The one-connections from 0 to 3 of the flow graph of Fig. 7.

$$b_k\Delta_{kl} = \Delta' = (-1)^n \sum_{\sigma} (-1)^{L_\sigma} C(G; 0 - l)_\sigma$$

where

$C(G; 0-l)_\sigma$ is the one-connection gain (*i.e.*, the product of the branch gains) of the σth one-connection from 0 to l of the flow graph G.

L_σ is the number of directed loops in the σth one-connection.

The summation is taken over all one-connections from 0 to l of G.

VI. General Formula

In general, there is more than one branch connecting the source node to the rest of the graph; obviously, in such cases the individual contributions of each such branch must be summed and the result takes this form:

Theorem 2: In order to solve for the variable x_l defined by the set of equations

$$\sum_{j=1}^{n} a_{kj}x_j = b_k \qquad (k = 1, 2, \cdots, n) \tag{1}$$

1) Set up the associated flow graph G as specified in Section II.
2) Draw all the connections of the flow graph G_0 (=graph G with source node 0 deleted) and list their connection gains: $C(G_0)_1$, $C(G_0)_2$, $\cdots$
3) Draw all the one-connections from the source node 0 to the node l of the graph G and list their one-connection gains: $C(G; 0-l)_1$, $C(G; 0-l)_2$, $\cdots$
4)

$$x_l = \frac{\sum_{\sigma} (-1)^{L_\sigma} C(G; 0 - l)_\sigma}{\sum_{\rho} (-1)^{L_\rho} C(G_0)_\rho} \tag{5}$$

where

L_σ = number of directed loops in the σth one-connection from 0 to l of the flow graph G.
L_ρ = number of directed loops in the ρth connection of G_0.
the summations are taken over all connections and one-connections from 0 to l of graphs G_0 and G respectively.

Example: Consider the system of equations,

$$\begin{cases} a_{11}x_1 + a_{12}x_2 + a_{13}x_3 = b_1 \\ a_{22}x_2 + a_{24}x_4 = 0 \\ a_{31}x_1 + a_{33}x_3 = b_3 \\ a_{42}x_2 = a_{43}x_3 + a_{44}x_4 = 0. \end{cases} \tag{6}$$

Let us solve for x_3. The graph G is shown on Fig. 7. All the connections of G are listed in Fig. 5(b). The one-connections from 0 to 3 of G are shown on Fig. 8 Then, by (5), we have

$$x_3 = \frac{b_3a_{11}a_{22}a_{44} - b_3a_{11}a_{42}a_{24} - b_1a_{31}a_{22}a_{44} + b_1a_{31}a_{24}a_{42}}{\Delta}$$

where

$$\Delta = a_{11}a_{22}a_{33}a_{44} - a_{12}a_{24}a_{43}a_{31} + a_{13}a_{31}a_{42}a_{24} - a_{11}a_{33}a_{42}a_{24} - a_{22}a_{44}a_{13}a_{31}.$$

The general expression (5) calls for two important comments.

Comment 1—*In general,* there can be no cancellation of terms in the algebraic sums of either the numerator or the denominator of (5).

The reason for this is quite obvious: Since each term is a connection gain (a one-connection gain) of a connection (one-connection) distinct from all the other connections (one-connections) there can, in general, be no cancellations; for it would imply the existence of special relationships between the gains of various branches.

There is, however, one simplification that any engineer worth his salt would instinctively take advantage of. Suppose x_1 is to be computed and suppose there are some node variables x_{k_1}, x_{k_2}, $\cdots$, x_{k_m} that have no effect on x_1, then these nodes may be deleted from the graph when x_1 is computed.

This idea can be expressed precisely if the following definition is introduced:

Definition 6—*A forward path* from p to q of the flow graph G is a connected subgraph whose branches b_1, b_2, $\cdots$, b_l can be ordered such that

1) the tip of b_k is the origin of b_{k+1} ($k=1, 2, \cdots, l-1$)
2) each node of the forward path has only one branch terminating to it and one branch originating from it, with the exception of p and q which, respectively, have only one branch originating and terminating to them.

A forward path from p to q can be obtained from each one-connection from p to q by deleting from the one-connections all the directed loops.

The second comment takes the form

Comment 2—When solving for x_1, delete from the graph G all the nodes x_{k_1}, x_{k_2}, $\cdots$, x_{k_m} which have the property that there is no forward path that connects each one of them to x_1.

Example: Consider the system

$$\begin{aligned} a_{11}x_1 + a_{12}x_2 &= 0 \\ a_{21}x_1 + a_{22}x_2 &= +b_2 \\ a_{32}x_2 + a_{33}x_3 + a_{34}x_4 &= 0 \\ a_{43}x_3 + a_{44}x_4 &= 0. \end{aligned}$$

The corresponding flow graph is shown in Fig. 9. It is obvious in this simple example, from the graph and from the equations, that the variables x_3 and x_4 may be disregarded in solving for x_1; also, there is no forward path from 3 to 1 and from 4 to 1.

A straightforward analysis shows that if the nodes $x_{k_1} \cdots x_{k_m}$ are not deleted, all the connection gains and the one-connection gains of (5) will have a common factor which will cancel from numerator and denominator. This leads to the very important conclusion that, provided the precaution of Comment 2 is taken into ac-

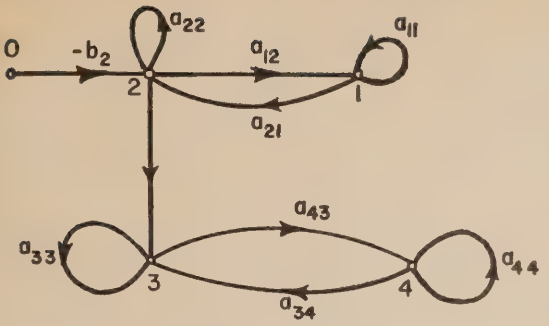


Fig. 9—Illustration of a flow graph that has no forward path from nodes 3 and 4 to node 1.

count, Theorem 2 gives the optimum gain formula for a flow graph.

Thus, the following important conclusion is reached: Given the problem of solving (1) by topological methods then, provided the Comment 2 is taken into account, the expression given in Theorem 2 is the simplest expression for the solution in terms of the b_k's and a_{ij}'s.

VII. The Relationship Between Signal-Flow Graphs (Mason) and Flow Graphs (Coates)

The process of association of a flow graph (Coates) to a set of equations has been described in detail in Section II. For reference let us note that the equations are written

$$\sum_{j=1}^{n} a_{kj}x_j = b_k \qquad (k = 1, 2, \cdots, n) \tag{1}$$

where

a_{kj} is the gain of the branch, directed from j to k, connecting node j to node k, and

$-b_k$ is the gain of the branch connecting the source node to node k.

Mason,[2] on the other hand, writes his equations thus:

$$\sum g_{kj}x_j = x_k + b_k \qquad (k = 1, 2, \cdots, n) \tag{7}$$

where

g_{kj} is the gain of the branch, directed from j to k, connecting node j to node k, and

$-b_k$ is the gain of the branch connecting the source node to node k.

Simply by looking at the equations we can see clearly that (1) and (7) will be identical if and only if

$$g_{kj} = a_{kj} \text{ if } k \neq j \quad \text{and} \quad g_{kk} - 1 = a_{kk}.$$

This gives the following rules:

1) To obtain a flow graph (Coates) from a given signal-flow graph (Mason), simply subtract one from the gain of each existing self loop and to each node of the signal-flow graph devoid of self loop, insert one with gain -1.

2) To obtain a signal-flow graph (Mason) from a flow graph (Coates), add unity to the gain of each existing self loop and to each node of the flow graph devoid of self loop, insert a self loop of gain $+1$.

Physically, we can interpret both graphs in terms of analog computer concepts:

A. Signal-Flow Graphs

Node variables x_j: potential of node j with respect to ground.

Gain g_{kj}: admittance of the branch connecting j to k, thus $g_{kj}x_j$ is a current entering node k.

Node: electronic summing amplifier: its output voltage is equal to the sum of the input currents:

$$x_k = \sum_{j=1}^{n} g_{kj}x_j - b_k \cdot 1.$$

Note that this summing amplifier does not invert the sign as is usually the case with analog computer amplifiers.

B. Flow Graphs

Node variables x_j: potential of node j with respect to ground.

Gain a_{kj}: admittance of the branch connecting j to k.

Node: operational amplifier with its feedback loop open; thus if the output voltage x_k is in the linear range, the sum of the input currents is negligibly small in view of the high gain of the amplifier; hence

$$\sum a_{kj}x_j - b_k \cdot 1 = 0.$$

Appendix

By definition, the determinant[4] of a matrix A is

$$\det A = \Delta = \sum_{P} (\operatorname{sgn} P) a_{1i_1} a_{2i_2} \cdots a_{ni_n}$$

where Σ/P denotes that the summation is taken only over the $n!$ permutations $i_1, i_2, \cdots, i_n$ of $1, 2, \cdots, n$ and (sgn P) is $+1$ or -1 depending on whether the permutation $i_1, i_2, \cdots, i_n$ is even or odd.

The key properties that are used in the paper are the following:

1) The interchange of any two adjacent symbols of a permutation changes the permutation into one of the opposite parity.

2) Exactly one element from each row and one element from each column appears in each term of the expansion of Δ.

3) If any two parallel lines (rows or columns) of A are interchanged, the determinant of the resulting matrix is $-\det A$.

A Broad-Band Cyclotron Resonance RF Detector Tube*

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Summary—**A tube is described which utilizes the cyclotron motion of electrons to provide a resonant system which is tuned by variation of the magnetic flux density. The amplitude of the cyclotron motion depends upon the relationship of the applied signal frequency and the electron cyclotron frequency; at resonance, the amplitude is maximum. Resonance is detected by shooting the spiraling electrons through a honey-comb type mesh grid; the current intercepted by the grid is greatest at resonance and is proportional to the RF signal power.**

The tube is a complete TRF receiver (less video amplifier) within one vacuum envelope. The resonant frequency is a linear function of solenoid current; the tube can be tuned over a wide frequency range (at least 10:1) with a single control. The characteristics of the device have been investigated for resonant frequencies from 65 to 650 mc; the sensitivity and 3-db RF bandwidth can be varied within limits; typical signal sensitivity is −45 dbm (500-kc video bandwidth) with a 4-mc 3-db RF bandwidth.

The measured characteristics and the theoretical predictions are in reasonable agreement.

INTRODUCTION

An electron beam, a static magnetic field parallel to the beam, and a perpendicular RF electric field may be combined to form a resonant system which can be tuned electronically over a wide frequency range. The application of this resonant system to the detection and frequency determination of RF signals had been explored by several investigators[1–3] and some tubes were constructed at Stanford University[4,5] prior to 1950. The sensitivity of these tubes was extremely poor, but it was nevertheless encouraging enough to support further efforts. From 1950 to 1954, tubes with much improved sensitivity were developed. Until recently, information concerning these tubes could not be widely disseminated due to security restrictions.

The cyclotron resonance detector tube, or cyclon detector tube, as it is sometimes designated, is essentially a nonamplifying resonant system followed by a detector; the resonant frequency of the system is the "cyclotron frequency"; the detector is a grid through which an electron beam is shot.

The cyclotron frequency is determined by the magnitude of the static magnetic field in which the electron beam is immersed. In one type of cyclotron resonance tube (the Spanatron) developed at Stanford,[6–10] the magnitude of the static magnetic field is made to vary spatially, in a known manner, across a sheet electron beam so that electrons in different sections of the beam have different resonant frequencies. The other, historically more recent, type consists of a pencil electron beam immersed in a uniform static magnetic field. Both types utilize the same basic phenomena. In the Spanatron, however, the frequency of an unknown signal is obtained by determining (with a detector grid) the section of the sheet beam that is in resonance with the unknown signal. Signal frequency is determined in the pencil beam tube by adjusting the magnitude of the uniform static magnetic field until resonance is indicated. This paper is concerned with the latter type of tube.

A photograph and a functional schematic representation of the cyclotron resonance detector tube to be described is shown in Figs. 1 and 2. A pencil electron beam is directed between the inner and outer conductors of a 50-ohm coaxial line. When an RF signal is applied to the coaxial line, an alternating electric field perpendicular to the beam is excited. If the RF frequency and the cyclotron frequency are nearly equal, the mutually perpendicular RF electric field and the uniform static magnetic field will cause individual electrons to spiral about axes parallel to the beam. The path radius of the spiralling electrons will be greatest when the RF fre-

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* Original manuscript received by the IRE, August 4, 1959; revised manuscript received, December 14, 1959. The work described here was sponsored by the U. S. Air Force under contract AF 33(600)-27784, with Stanford University. This work is also based on previous research made possible through support extended to Stanford University by the U. S. Air Force, U. S. Army Signal Corps, and the U. S. Navy (Office of Naval Research, Bureau of Aeronautics, and Bureau of Ships).

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[2] S. F. Kaisel, "Analysis of a Proposal for a Non-Scanning Radio-Frequency Spectrum Analyzer," Electronics Res. Lab., Stanford University, Stanford, Calif., N6onr 25107; September 1, 1947.

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[9] L. A. Roberts, "The Extension of the Design for a Non-Scanning Microwave Intercept Receiver," Electronics Res. Lab., Stanford University, Stanford, Calif., Tech. Rept. No. 1, N6onr 25132; May 15, 1951. This was also a Ph.D. dissertation under the same title.

[10] W. G. Worcester, "An Investigation of Electrical Detection Methods for a Non-Scanning Microwave Spectrum Analyzer," Electronics Res. Lab., Stanford University, Stanford, Calif., Tech. Rept. No. 2, N6onr 25132; February 15, 1952. This was also a Ph.D. dissertation under the same title.

quency, as viewed by an observer moving at the axial velocity of the electrons, is equal to the cyclotron frequency. To detect the spiral motion of the electrons, the beam is passed through a grid which is composed of many honeycomb-like cells (Fig. 3); some electrons are captured by the grid. If the path radii of the spiralling electrons are relatively small, most of the beam will pass through the detecting grid to the collector. If the path radii of the electrons are increased, fewer of the electrons in the beam will reach the collector. Thus, a current whose amplitude is sensitive to the path radii of the electrons may be obtained either from the detecting grid or from the collector.

The characteristics of a detecting grid were first investigated by Roberts[9] and Worcester;[10,11] Stewart subsequently completed a statistical theory of detector grid behavior. Stewart[12–15] also proposed and built cyclotron resonance detector tubes utilizing a coaxial line interaction structure. The tubes described here are refinements of Stewart's early models.

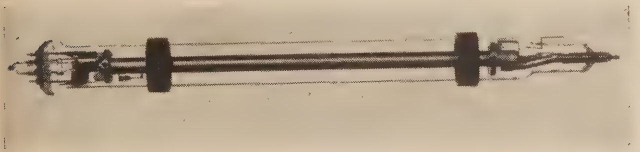

Fig. 1—Cyclotron resonance detector tube. Overall dimensions, $14\frac{5}{8}\times 1\frac{11}{32}$ inches.

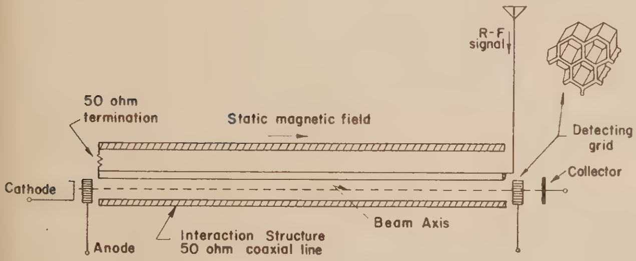

Fig. 2—Cyclotron resonance detector tube, functional schematic.

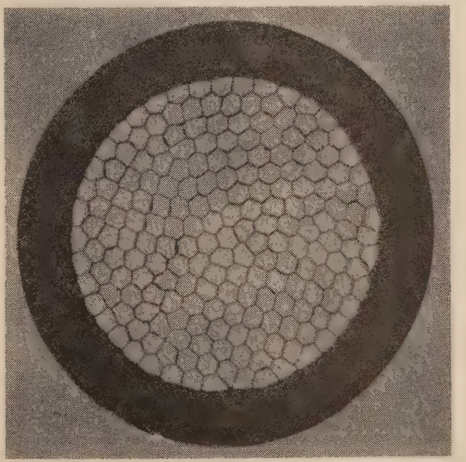

Fig. 3—Honey-comb detecting grid. Hexagonal cell diameter and depth, approximately 10 mils.

In the following portions of this paper a simplified analysis of the energy transfer from the RF electric field to the spiralling electrons will be presented, the mechanical details of the tube will be outlined, and the electrical characteristics, both predicted and measured, will be discussed. The theory of the detecting grid is presented elsewhere; only the observed characteristics of one particular grid are reported here.

DESCRIPTION OF CYCLOTRON RESONANCE DETECTOR TUBE

This section describes the mechanical details of a cyclotron resonance detector tube and typical operational procedures.

Construction of the tube is not difficult; many of the parts can be purchased commercially and those requiring fabrication are not complex. The tube is rugged, reliable, and simple to operate.

A major component of the tube is the 10-inch coaxial-line interaction structure. It is nonmagnetic stainless steel tubing; the inside diameter of the larger tubing is 0.36 inch, while the outside diameter of the smaller tubing is 0.15 inch. The outer coaxial cylinder is supported within the glass envelope by two support rings. Each support ring contains three synthetic sapphire balls (one of which is spring-loaded) which bear against the glass envelope. The tubing forming the inner coaxial conductor is supported at the gun end of the tube by an Aquadag coated glass bead. The glass bead, visible in Fig. 1, serves not only as a mechanical support, but also as the 50-ohm termination for the coaxial line.

The external RF connection to the tube is made at a coaxial Kovar seal near the collector. A short section of internal coaxial transmission line connects the interaction structure to the Kovar seal. RF is brought in at the collector end of the tube, not only to reduce the overall diameter of the tube, but also to keep the magnetic Kovar as far from the beam as possible.

A standard RCA cathode-heater assembly with a flat 0.12-inch oxide-coated cathode button provides the electron source. Both the anode and the detecting grid, which are mounted perpendicular to the beam, are of the type shown in Fig. 3. These grids, made available

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[11] Subsequent to his work at Stanford, Worcester and his associates at the Engrg. Exp. Sta., University of Colorado, Boulder, have continued the study of cyclotron resonance, with particular emphasis on the Spanatron. Tech. Repts. 1–7, Nonr-1147-01, describe their work during the 1953–1958 period.

[12] J. L. Stewart, "The Analytical Theory of Cyclotron Resonance Video Detectors and Mixers with Examples," Electronics Res. Lab., Stanford Unversity, Stanford, Calif., Tech. Rept. No. 17, N6onr 25123; September 25, 1952. This was also a Ph.D. dissertation under the same title.

[13] J. L. Stewart, "The Theory of Cyclon Detectors and Mixers," Electronics Res. Lab., Stanford University, Stanford, Calif., Tech. Rept. No. 19, N6onr 25132; April 10, 1953.

[14] J. L. Stewart, "New Cyclon Detectors," Electronics Res. Lab., Stanford University, Stanford, Calif., Tech. Rept. No. 23, N6onr 25132; June 26, 1953.

[15] J. L. Stewart, "Electron flow through small tubes with magnetic focusing," *J. Appl. Phys.*, vol. 24, pp. 1236–1240; September, 1953.

through the courtesy of Varian Associates, have a cell diameter and depth of approximately 0.010 inch.

Typical applied potentials and resulting currents are: coaxial interaction structure, zero volts dc (outer conductor grounded); useful cathode voltage range, -3 to -15 volts; cathode current, 50–60 μa; collector current (in the absence of RF), 5–15 μa; dc collector potential, a few volts above ground (not critical); detecting grid, ground potential.

The beam voltage at which the tube is to be operated is chosen on the basis of RF bandwidth and sensitivity considerations (see Figs. 8 and 9); the anode potential is set one volt positive with respect to the cathode, and the tube's position in the magnetic field is adjusted to secure maximum collector current in the absence of a signal. A slight spatial re-alignment of the tube in the magnetic field, and adjustment of the anode potential, may be required to obtain maximum sensitivity when a test signal is applied.

The required magnetic field was generated by a wire-wound solenoid $16\frac{1}{2}$ inches in length and $4\frac{1}{2}$ inches in outside diameter. A reasonable amount of care must be exercised during construction of the solenoid to obtain winding uniformity. At a cyclotron frequency of 650 mc (232 gauss), the solenoid dissipated approximately 40 watts; a 1-ma change in the solenoid current varied the cyclotron frequency 3 mc.

Detection of Spiralling Electrons

The most satisfactory method discovered so far for detecting spiralling electrons is a honey-comb grid of the type shown in Fig. 3. It appears from geometrical considerations that, as a first approximation, the probability of electron interception by the detecting grid would be directly proportional to the radius of the electron's helical path. Observations indicated that this was not true; grid detection is more complicated than one might suspect. Consideration of the random phenomena created by the electrostatic field near the grid, and by thermal factors, suggested that a statistical approach to the problem might be fruitful. Both Worcester[10] and, more recently, Stewart[12,13,15] have analyzed detecting of grid behavior from a statistical viewpoint. Both these analyses correctly indicate that the change in intercepted current will be nearly proportional to the square of the signal-induced radius under small-signal conditions. That this is so may be inferred from Fig. 6 and (9). The actual sensitivity realized by the detecting grids is within a few db of that which is theoretically possible according to Stewart's analysis. For more details on the theoretical behavior of the honey-comb grids, the reader is referred to the references cited.

Theoretically the signal is negative at the detector grid (grid intercepts electrons) and positive at the collector; thus, it would seem, one would have a choice of video signal polarity. In practice, however, some detection occurs in the interaction structure; *i.e.*, some electrons spiral into the conductors of the RF transmission line. Near the lower frequency limit of the tube described, the detected signal at the grid may change polarity—due to interception of electrons in the interaction structure. Since the polarity of the signal at the collector is always the same, it was used rather than the grid signal.

Energy Transfer Mechanism

An electron entering the coaxial interaction structure with only an axial velocity would, in the absence of an RF signal, follow a straight-line trajectory parallel to the beam axis. However, should the electron acquire a velocity component transverse to the axial magnetic field, due to thermal emission effects, the RF field, or from any cause whatsoever, the electron trajectory will not be a straight line. The electron will instead spiral about a line parallel to the beam axis; in addition to its axial velocity, it will have acquired an angular velocity. Thus, the electron trajectory may be visualized as a helix of constant pitch with an axis parallel to the static axial magnetic field. The number of revolutions the spiralling electron completes each second (the cyclotron frequency) is uniquely determined by the magnetic flux density.

If the frequency of the RF field, as viewed by an observer moving at the axial velocity of the electron, is equal to the cyclotron frequency and if the phase relationship of the spiralling electron and the RF field is optimum, the electron will continuously gain energy from the transverse electric field. The radius of the spiralling electron will continuously increase as the electron moves through the interaction structure. If the observed RF frequency differs from the cyclotron frequency, the electron gains less energy, its path radius is less, and the current intercepted by the detector grid is less. Hence, the spiralling electrons form a resonant system. It is the purpose of the ensuing analysis to determine the characteristics of this resonant system.

In order to simplify the analysis, the terminated coaxial line structure used in the actual tube is replaced by a lossless, terminated parallel-plate transmission line in which all fringing fields are neglected. The parallel-plate structure and assumed coordinate system are shown in Fig. 4. The RF electric field is entirely in the y direction and independent of the x coordinate; the uniform static magnetic field is in the $+z$ direction only. A partial list of the symbols used follows (mks units are used unless otherwise noted).

B = axial magnetic flux density,
e = electronic charge,
E_y = instantaneous RF electric field $= E_0 \cos(\omega t + \beta z + \phi)$,
E_0 = maximum value of RF electric field,
m = electron mass,
u_0 = z-directed electron velocity,
v = RF phase velocity,
β = RF phase constant,

ϕ = phase angle relating value of RF electric field and angular position of electron at $t=0$, *i.e.*, $-E_0 e \cos\phi$ is force acting on electron at $t=0$,
ω = angular frequency of RF input ($\omega = 2\pi f$),
ω_c = cyclotron angular frequency ($\omega_c = 2\pi f_c$),
ω_k = angular frequency of RF input viewed by moving electron, and
τ = electron transit time through interaction space.

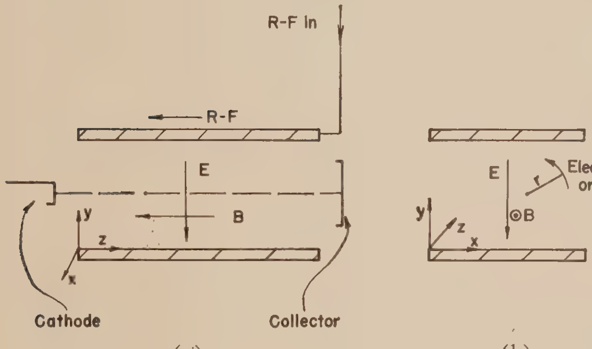
Neglecting the effects of other electrons, *i.e.*, space charge, it is well known that an electron having a velocity component perpendicular to a static magnetic field will, under equilibrium conditions, perform a circular motion having an angular velocity:

$$\omega_c = 2\pi f_c = \left| \frac{e}{m} B \right|,$$

where f_c = cyclotron frequency in cps.

The incremental energy gained by the orbiting electron from the RF electric field (see Figs. 4 and 5) is:

$$dW = \boldsymbol{F} \cdot \boldsymbol{ds} = -E_y e r \omega_c \cos \omega_c t \, dt. \tag{1}$$



(a) (b)

Fig. 4—Parallel-plate interaction structure, side and end views.

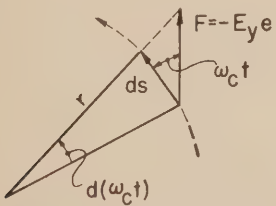


Fig. 5—Electron force diagram.

Since the energy of a spiralling electron is

$$W = \tfrac{1}{2} m r^2 \omega_c^2, \tag{2}$$

then

$$dW = m r \omega_c^2 dr.$$

Eliminating dW from (1) and (2),

$$dr = \frac{E_y}{B} \cos \omega_c t \, dt = \frac{E_0}{B} \cos(\omega t + \beta z + \phi) \cos \omega_c t \, dt. \tag{3}$$

The electron enters the interaction structure at $z = t = 0$. The z coordinate of the electron is $z = u_0 t$, so that $\beta z = \omega / v(u_0 t)$. Eq. (3) may be written

$$dr = \frac{E_0}{B} \cos(\omega_k t + \phi) \cos \omega_c t \, dt, \tag{4}$$

where

$$\omega_k \overset{\Delta}{=} \omega \left(1 + \frac{u_0}{v} \right).$$

If the amount of energy absorbed by the electron is small, E_0 can be assumed constant. Integrating (4) over the time interval 0 to τ, where τ is the electron transit time, one obtains

$$\begin{aligned} r &= \left| \frac{E_0 \tau}{2B} \left(\frac{\sin(\omega_c \tau - \omega_k \tau - \phi) + \sin \phi}{(\omega_c - \omega_k)\tau} + \frac{\sin(\omega_c \tau + \omega_k \tau + \phi) - \sin \phi}{(\omega_c + \omega_k)\tau} \right) + r_0 \right| \\ &= |r_s + r_0| . \end{aligned} \tag{5}$$

In this equation,

r = total electron path radius at $t = \tau$,
r_0 = initial electron path radius prior to electronic interaction, and
r_s = component of electron path radius due to electronic interaction with RF field.

The absolute magnitude of (5) is taken since a negative value of r has no physical significance.

If the assumption is made that $(\omega_c + \omega_k) \gg |\omega_c - \omega_k|$, (5) can be written

$$r = \left| \frac{E_0 \tau}{2B} \, \frac{\sin \frac{\Delta\omega\tau}{2}}{\frac{\Delta\omega\tau}{2}} \cos\left(\phi - \frac{\Delta\omega\tau}{2} \pm 2n\pi \right) + r_0 \right|,$$

$$n = 0, 1, 2, \cdots, \quad \text{and} \quad \Delta\omega = \omega_c - \omega_k. \tag{6}$$

Application of the assumption noted invalidates (6) near the zeros of the $(\sin \Delta\omega\tau/2)/(\Delta\omega\tau/2)$ term. The equation can be used, however, to describe the maximum value of $|r|$ as a function of the pertinent variables.

Presumably all values of ϕ are possible in an actual tube so that the maximum possible electron path radius as a function of $\Delta\omega\tau$ is observed by the detecting grid. This radius is

$$r = \left| \frac{E_0 \tau}{2B} \left| \frac{\sin \frac{\Delta\omega\tau}{2}}{\frac{\Delta\omega\tau}{2}} \right| + r_0 \right| . \tag{7}$$

Maximum radius is obtained at $\Delta\omega = 0$; resonance, therefore, occurs when $\omega_c = \omega_k$, *i.e.*, when

$$f_c = f\left(1 + \frac{u_0}{v}\right). \tag{8}$$

The factor $(1 + u_0/v)$ represents the increase in the signal frequency (f) as "seen" by the electron due to the Doppler effect. If the RF wave on the parallel-plate transmission line were a standing-wave rather than a traveling-wave, resonance would occur at $f = f_c$.

The electron path radius at resonance is

$$r_m = \left| \frac{E_0\tau}{2B} + r_0 \right|. \tag{9}$$

Taking the ratio of (7) and (9) gives the relative electron-path radius with respect to the resonant radius. Assuming that the initial radius r_0 is small compared to the signal induced radius, this ratio becomes

$$\frac{r}{r_m} = \left| \frac{\sin \frac{\Delta\omega\tau}{2}}{\frac{\Delta\omega\tau}{2}} \right|. \tag{10}$$

Both experimental and theoretical considerations indicate that the detecting grid output varies as the square of the electron path radius. Squaring (10), therefore, gives the relative response curve of the device as the signal frequency varies. If the signal frequency is held constant, and the magnetic field (cyclotron frequency) is varied, the response curve is given by the square of (10), provided $\Delta\omega$/resonant angular frequency $\ll 1$.

Eq. (10) has decreased to 0.707 of its maximum value when $\Delta\omega\tau/2 = 1.39$; the 3-db bandwidth is, therefore,

$$\Delta f_{3\text{db}} = \frac{\Delta\omega}{\pi} = \frac{2.78}{\pi\tau}\cdot \tag{11}$$

Since the energy transferred to a resonant electron is given by $\frac{1}{2}m(E_0\tau/2B)^2\omega_c^2$, the power transferred to a beam is

$$P_c = \frac{e}{m} I \frac{(E_0\tau)^2}{8}, \tag{12}$$

where I = beam current, and P_c = power transferred to the beam.

It will be noted from the preceding analysis that the resonant electron path radius is proportional to the product of the peak value of RF field and electron transit time [see (9)]. Once one has decided upon an interaction structure, the peak value of the transverse electric field is fixed for a given signal power input. Transit time, however, can be controlled by adjustment of the beam voltage.

Increasing the electron transit time (decreasing the beam voltage) decreases the signal power required to attain a given resonant radius, and at the same time, decreases the 3-db bandwidth [see (11)]. As one might suspect, there is a practical limit as to how far the transit time may be increased. Experimentally, the minimum useful beam voltage has been determined to be approximately 3.5 volts for the 10-inch coaxial-tube line. This corresponds to a minimum 3-db bandwidth of about 4 mc. The 3-db bandwidth, as indicated by (11), has been found to be essentially independent of the resonant frequency, at least over the 10:1 frequency range investigated. Similarly, the power coupled to the beam at resonance is independent of frequency. Eq. (12) also indicates that the frequency range over which power can be satisfactorily coupled to the beam is determined only by the frequency characteristics of the interaction structure.

In arriving at (10), which describes the relative electron path radius, it was assumed that all values of ϕ are possible because the time-relationship of electron entry and the peak RF field is random. Some electrons will, therefore, always acquire the maximum possible energy as the signal frequency varies about the cyclotron frequency. The response for off-resonance frequencies would, under these conditions, decrease in relative amplitude at the slowest possible rate; *i.e.*, the response given by (10) has the worst possible selectivity for this resonant system.

One is therefore led to inquire as to the possibility of obtaining a more selective response characteristic. Such a possibility exists; for $\phi = 0$, (10) becomes:

$$\frac{r}{r_m} = \left| \frac{\sin \Delta\omega\tau}{\Delta\omega\tau} \right|, \tag{13}$$

where r_m is given by (9). The 3-db bandwidth obtained for $\phi = 0$ is exactly one-half of that given by (11).

CHARACTERISTICS OF THE CYCLOTRON RESONANCE DETECTOR TUBE

The tube responds to CW, AM, and FM signals; for convenience, however, pulsed signals were generally used in determining the characteristics described in this section.

The relative amplitude of detected RF pulses as a function of the peak RF power input is shown in Fig. 6. The detection is square law over the region where the slope of the curve is one, *i.e.*, over a power input range of 20 db. Saturation occurs at approximately 1/10 of a milliwatt; the input RF power dynamic range is approximately 35 db. The data for Fig. 6 were taken at resonance with a beam voltage of 4.0 volts at an RF input frequency of 230 mc. The detector characteristic observed at other frequencies (100 and 500 mc) is not significantly different from that shown in Fig. 6.

The relative response curve for the tube is shown in Fig. 7; the solid curve represents the actual response, while the dashed curves are the envelopes of the two the-

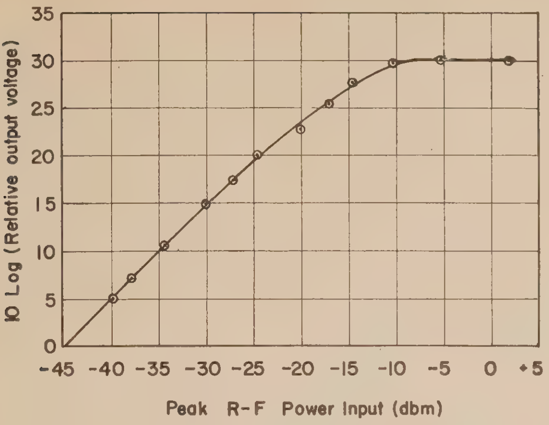


Fig. 6—Grid detector characteristic.

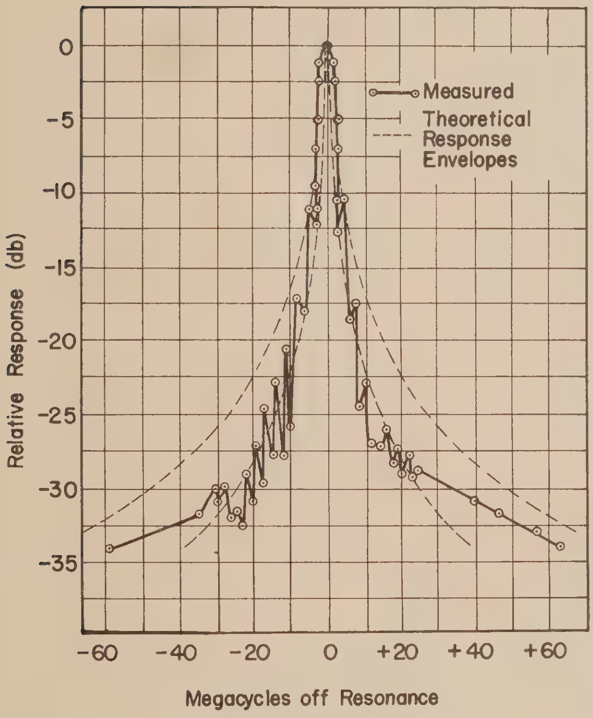


Fig. 7—Cyclotron resonance relative response curve.

oretical response characteristics obtained from (10) and (13), assuming the detector grid responds to the square of the relative electron path radius. Due to the assumption noted in connection with (6), only the envelope of the theoretical responses (curve through maximum values of $|r/r_m|^2$) is shown in Fig. 7. The outer dashed curve is (10) squared and represents the envelope of the response one would expect to obtain; the inner, more sharply resonant, dashed curve is shown merely to indicate a more desirable response which is, at least theoretically, obtainable. Inspection of Fig. 7 shows that the agreement between experiment and theory is reasonable, but by no means perfect. Assumptions involved in the analysis and the experimental error probably account for the discrepancy.

The characteristic shown in Fig. 7 is typical of the response curves observed for resonant frequencies greater than 100 mc. In the region of 100 mc and below, the response becomes noticeably asymmetric for reasons not clearly understood.

The selectivity of the resonant system is not particularly impressive: the 30-db/3-db bandwidth ratio is only about 14. One obvious means of improving the selectivity is to provide RF pre-selection ahead of the tube. For operation over an extensive frequency range, as well as for ease in tracking, the pre-selector also probably should be a device which utilizes the cyclotron resonance phenomena. Perhaps a device patterned after the Cuccia electron coupler[16,17]—but with wide-band transmission line input and output interaction-structures—would be an effective pre-selector.

The 3-db RF bandwidth as a function of beam voltage is shown in Fig. 8. The solid curve is plotted from measured data; the dashed curve is calculated from (11). The electron transit-time required for substitution in (11) was calculated on the basis of a 10-inch interaction length and an average axial velocity, u_0, given by the relation $\frac{1}{2}mu_0^2 = eV$, where V is the cathode voltage. The predicted and measured curves are nearly parallel for beam voltages greater than 3.5 volts, thus, at least qualitatively, providing verification of (11) in this region.

The abrupt change in the general trend of the solid curve in Fig. 8 at beam voltages of 3.5 volts and less is correlated with a similar change in the sensitivity-beam voltage characteristic (see Fig. 9).

Since the electron path radius at resonance is proportional to the transit time [see (9)], it is to be expected that sensitivity will decrease with an increase in beam voltage. In Fig. 9 the tangential signal sensitivity for a 1-μsec pulse (500-kc video bandwidth[18]) is plotted as a function of beam voltage. At beam voltages of 3.5 volts and less, the general trend of the curve is reversed: in this region the tube also becomes acutely sensitive to minor changes in operating conditions. It is customary, therefore, to operate the tube at a beam voltage of four or even five volts when maximum sensitivity is desired.

The sensitivity-beam voltage characteristic is essentially independent of frequency, at least over the 65–650-mc range examined. The ordinate (sensitivity) will change with resonant frequency. The shape of the curve and of the abscissa, however, remain intrinsically unchanged.

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[16] C. L. Cuccia, "The electron coupler—a developmental tube for amplitude modulation and power control at ultra-high frequencies—Part I," *RCA Rev.*, vol. 10, pp. 270–303; June, 1949.

[17] C. L. Cuccia, "The electron coupler—a developmental tube for amplitude modulation and power control at ultra-high frequencies—Part II," *RCA Rev.*, vol. 14, pp. 72–99; March, 1953.

[18] The post-detection (video) amplifier bandwidth must be chosen so as to amplify the detected modulation with satisfactory fidelity. This bandwidth will in turn affect the video amplifier noise and thereby the minimum detectable RF signal.

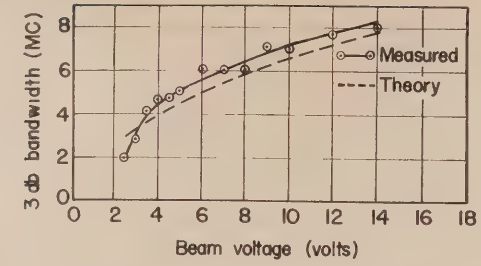

Fig. 8—3-db RF bandwidth vs beam voltage.

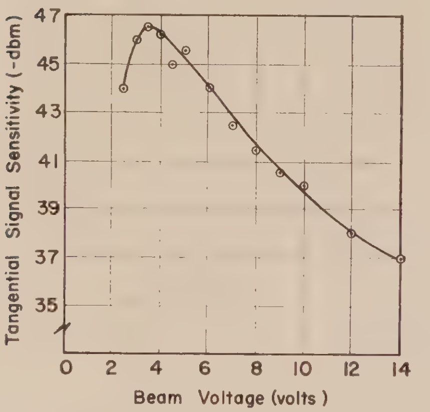

Fig. 9—Tangential signal sensitivity vs beam voltage, 500-kc video bandwidth.

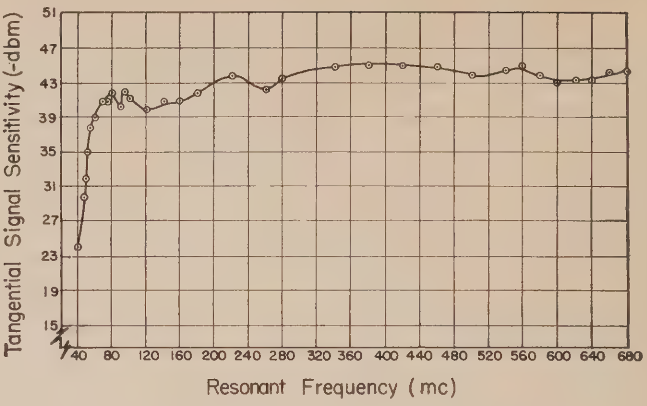

Fig. 10—Tangential signal sensitivity vs resonant frequency, 500-kc video bandwidth and 5-mc RF bandwidth.

The wide frequency range over which the cyclotron resonance detector tube can be operated is indicated in Fig. 10. The resonant frequency was varied by changing the current in the solenoid windings; no other adjustment was made. The sensitivity gave no sign of decreasing above 680 mc; data were not taken at higher frequencies because of solenoid dissipation. The sensitivity shown in Fig. 10 is for an RF bandwidth of 5 mc (5-volt beam) and for a 1-μsec pulse (500-kc video bandwidth).

The poor sensitivity of the tube at the lower frequencies appears to be due primarily to beam transmission difficulties. At 56 mc, for example, the axial magnetic flux density required for resonance is only about 20 gauss. The useful low-frequency limit for these tubes would appear to be about 65 mc; operation near this low frequency limit requires that the solenoid be carefully shielded from the earth's magnetic field.

RF pre-amplification can be used to improve upon the basic sensitivity of the cyclotron resonance tubes. Low-noise, wide-band distributed amplifiers have been employed to obtain tangential signal sensitivities of −90 to −95 dbm over wide frequency ranges.

One of the unusual features of these tubes, possibly unique, is the electronically variable RF 3-db bandwidth. Fig. 8 would indicate that one need only vary the beam voltage to attain a desired 3-db bandwidth. It is true that the beam voltage controls the bandwidth, but usually a slight adjustment of anode voltage (and possibly of the tube's spatial alignment) is required to obtain maximum sensitivity following a change in the beam voltage. At most, the adjustments would take a few minutes; it might, however, be useful if one were able to change the bandwidth rapidly. This can be accomplished by distorting the axial magnetic field so as to achieve an effect analogous to staggered tuning.

The interaction structure of the cyclotron resonance tube and the magnetic field in which the tube is immersed are analogous to a resonant circuit which is tuned by varying the magnetic flux density. If the magnetic flux density over one-half the length of the interaction structure is different from that of the other half, the situation is analogous to that of two tuned circuits of different resonant frequencies connected in series. (In bandpass-amplifier theory, this combination would be called a "staggered pair.") Perhaps the simplest way to achieve a staggered magnetic field is to add a second winding to the solenoid which is wound clockwise for half the length of the solenoid and counter-clockwise for the remaining half. A current flowing in this winding will produce, ideally, an axial magnetic field which adds to the main field over one-half the length of the solenoid and subtracts from the main field over the other half. Since the added winding need only produce a magnetic field on the order of one or two gauss, the additional power required is negligible.

With the proper current flowing in the additional solenoid winding, a response curve with three peaks is obtained (see insert of Fig. 11). This response is nearly independent of the resonant frequency, as long as the beam voltage and the current in the additional winding remain unchanged. To change from the response of Fig. 7 to the three-peaked response of Fig. 11, one need only throw a switch to send a predetermined current through the additional winding. If the beam voltage is changed by more than 10 per cent, it is necessary to adjust the value of this current to obtain maximum results.

In Fig. 11 the 3-db bandwidths for the uniform and staggered magnetic fields are compared. The bandwidth is increased by a factor of approximately 3 (theoreti-

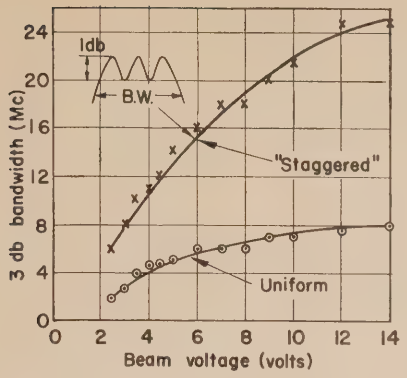

Fig. 11—3-db RF bandwidth vs beam voltage, uniform and "staggered" magnetic field.

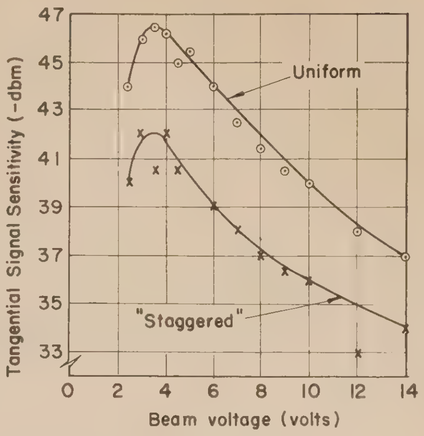

Fig. 12—Tangential signal sensitivity vs beam voltage, uniform and "staggered" magnetic field.

cally, 2.8) when the magnetic field is staggered. The increased bandwidth is acquired at the expense of sensitivity; the reduction of sensitivity (see Fig. 12) varies between 3 and 5 db depending upon the beam voltage.

The cyclotron resonance tubes are relatively immune to damage by high RF powers. Permanent damage is most likely to occur first at the terminating resistance. A small change in the value of the coaxial line termination is not detrimental. However, a large VSWR on the coaxial line would narrow the frequency range over which satisfactory sensitivity could be obtained. RF power of a magnitude far less than that which could cause any possible physical damage does, however, produce undesirable spurious responses.

If the RF input is sufficient to saturate the tube, that is, if it is greater than −10 dbm, spurious responses—which have no apparent relationship to the applied signal frequency—appear over a wide frequency range. These responses are at least 30 db below the peak of the main response and are easily identifiable. A second type of spurious response—which may have more serious consequences—is observed when the input power exceeds approximately −20 dbm. This response occurs when the cyclotron frequency is approximately half of the signal frequency: its amplitude is also at least 30 db below the main response, but the shape of its response-curve appears to be very similar to that of the main response (Fig. 7); hence, it can be mistaken for a weak legitimate signal.

CONCLUSIONS

The idealized and simplified theory of energy transfer presented in this paper—along with the results from an analysis of detecting grid behavior[13]—is sufficient to predict many of the characteristics of a cyclotron resonance detector tube.

The cyclotron resonance tubes are characterized by an extremely broad frequency range (at least 10:1) over which operation is possible. Resonance may be electronically varied; tuning is linear and may be accomplished either with a single manual control, or by periodic variation of the solenoid current (automatic frequency scanning). The sensitivity, RF bandwidth, dynamic range, and selectivity of this device should prove adequate for many purposes.

ACKNOWLEDGMENT

The author wishes to express his appreciation to L. D. Buchmiller for his suggestions and comments concerning the material in this manuscript. The author also desires to acknowledge the skill of H. R. Andrews, who constructed the tubes described.

The Stanford-developed cyclotron resonance tubes could not have been brought to their present state without the contributions of many people. In particular, the work of S. F. Kaisel, L. A. Roberts, W. G. Worcester, and J. L. Stewart was indispensable.

Anomalies in the Absorption of Radio Waves by Atmospheric Gases*

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Summary—**This paper summarizes recent measurements of the attenuation of radio waves by atmospheric gases and compares the measured losses with those predicted by Van Vleck. Reasonably good agreement has been noted between the predicted and measured losses for oxygen, but the measured loss for water vapor is considerably in excess of that predicted. Various factors which may influence this discrepancy are discussed.**

INTRODUCTION

In two classic papers in 1947, Van Vleck[1,2] evaluated the experimental evidence available on the absorption characteristics of atmospheric gases and predicted the magnitude of the attenuation of radio waves due to oxygen and water vapor. These papers have served as the starting point for most subsequent work in the field and the numerical predictions have been used frequently to estimate propagation losses.

The absorption of energy from a radio wave by atmospheric gases is due to the transition from one molecular rotation energy level to another caused by the electromagnetic wave. For gases at very low pressures, this energy change is associated with a very narrow band of frequencies. For increased pressures, the energy is absorbed over a wider range. The frequency dependence of microwave absorption was given by Van Vleck and Weisskopf[3] and the Van Vleck-Weisskopf equation as given in the Appendix has been the most commonly used means of predicting atmospheric losses.

Two critical constants are involved in each energy level transition. The first of these is the frequency associated with the energy transition. This may be determined from a knowledge of the energy levels or from direct measurement. Since the energy differences are very small for absorption lines in the microwave spectrum, the error involved in taking the difference of two nearly equal values is large. For this reason, direct measurement of resonant frequency is preferable where possible.

The second critical number is the line breadth constant associated with the frequency spread of the absorption. This value should be determined by direct measurement for the most reliable results.

VAN VLECK'S CHOICE OF LINE BREADTH CONSTANT

At the time of Van Vleck's papers, no propagation test had been made through the actual atmosphere in the millimeter wavelength region, and only a very few quantitative data were available in the centimeter region. On the basis of infrared studies, it had been possible to establish the molecular energy levels and the frequencies associated with their differences.

Oxygen losses in the millimeter spectrum result from the interaction of the magnetic moment of the O_2 molecule with the electromagnetic field. Transitions to the ground state occur with corresponding wavelengths grouped around 0.5 cm, and with one transition wavelength at 0.25 cm. In addition, nonresonant or Debye absorption provides a continuous spectrum of loss.

For line breadth constants of 0.05 or greater, the lines in the 5-mm wavelength band blend together to form a single line. On the basis of measurement of oxygen losses near 5 mm in waveguides by Berringer,[4] Van Vleck concludes that the appropriate line breadth constant should be 0.02 cm^{-1} at one atmosphere. The losses calculated, using this constant, were plotted in Fig. 1. The attenuation curve is somewhat irregular at the first peak but the details are masked by the log-log scale.

Measurements by Lamont[5] of oxygen losses around 5 mm through the actual atmosphere were found to be adequately explained by the use of the line breadth of 0.02 cm^{-1}. Laboratory measurements by Strandberg, *et al.*,[6] on pure oxygen and oxygen-nitrogen mixtures agreed with a line breadth constant between 0.015 and 0.02 cm^{-1}.

For water vapor, one line occurs near 1.35 cm and one at 1.63 mm. In addition, there are a vast array of lines in the near millimeter region. Ghosh and Edwards[7] have listed 588 of these absorption lines. Of these, 149 with significant line strength have wavelengths between 0.05 and 1.0 mm. The direct measurement of the line breadth constant has been possible only for the 1.35-cm line. Van Vleck concluded, on the basis of resonant cavity measurements by Becker and Autler[8] at Columbia Uni-

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* Original manuscript received by the IRE, August 11, 1959; revised manuscript received, December 14, 1959. This work was sponsored by the Office of Naval Research under Contract Nonr 375(01).

† Electrical Engineering Research Lab., University of Texas, Austin.

[1] J. H. Van Vleck, "The absorption of microwaves by oxygen," *Phys. Rev.*, vol. 71, pp. 413–424; April 1, 1947.

[2] J. H. Van Vleck, "The absorption of microwaves by uncondensed water vapor," *Phys. Rev.*, vol. 71, pp. 425–433; April 1, 1947.

[3] J. H. Van Vleck and V. F. Weisskopf, "On the shape of collision-broadened lines," *Rev. Mod. Phys.*, vol. 17, pp. 227–236; April–July, 1945.

[4] E. R. Beringer, "The absorption of one-half centimeter electromagnetic waves in oxygen, *Phys. Rev.*, vol. 70, pp. 53–57; July, 1946.

[5] H. R. L. Lamont, "Atmospheric absorption of microwaves," *Phys. Rev.*, vol. 74, p. 353; August, 1948.

[6] M. W. P. Strandberg, C. Y. Meng, and I. G. Ingersoll, "The microwave spectrum of oxygen," *Phys. Rev.*, vol. 75, pp. 1525–1528; May, 1949.

[7] S. N. Ghosh and H. D. Edwards, "Rotation Frequencies and Absorption Coefficients of Atmospheric Gas," Geophys. Res. Directorate, AF Cambridge Res. Ctr., Bedford, Mass., Rept. No. 82; March, 1956.

[8] G. E. Becker and L. H. Autler, "Water vapor absorption of electromagnetic radiation in the centimeter wave-length range," *Phys. Rev.*, vol. 70, pp. 300–307; September 1 and 15, 1946.

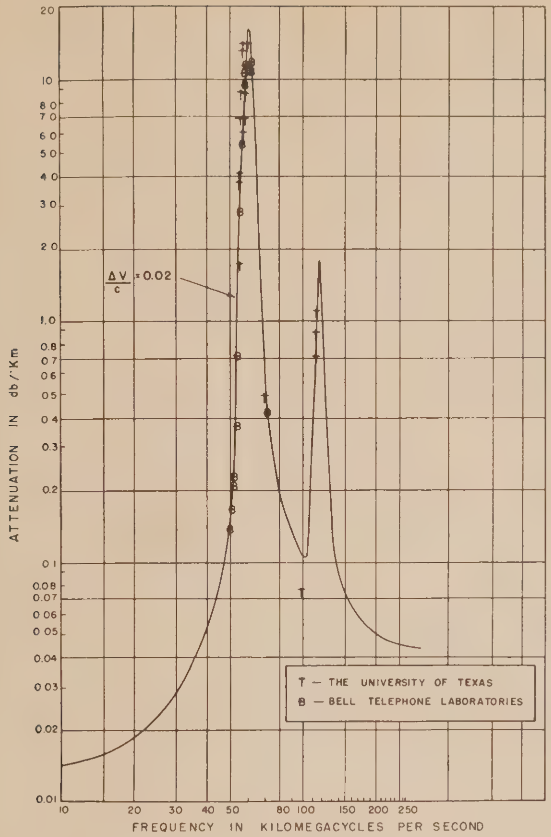

Fig. 1—Attenuation due to oxygen at one atmosphere.

versity, that this line breadth constant should be approximately 0.1 cm^{-1}. The assumption was made that this line breadth constant was the same for all water vapor lines and the spectral distribution of the water vapor losses was calculated. This theoretical attenuation as a function of frequency is shown in Fig. 2 for the line breadth constant of 0.1 cm^{-1} and also for a line breadth constant of 0.27 cm^{-1}.

Difficulties in Direct Transmission Loss Measurements

It is rather surprising that there are very few reports in the technical literature of quantitative measurements of absorption by atmospheric gases on actual transmission paths. Dicke's[9] radiometric measurement of the sun at 1, 1.25 and 1.50 cm provided estimates of the water vapor loss, but required a knowledge of the water vapor distribution with height which can only be approximated.

The problem in millimeter measurements has been the lack of generators of sufficient power to make actual transmission tests. In recent years, however, improvements in millimeter techniques have extended the range over which propagation measurements could be made, and data are available at a good many frequencies.

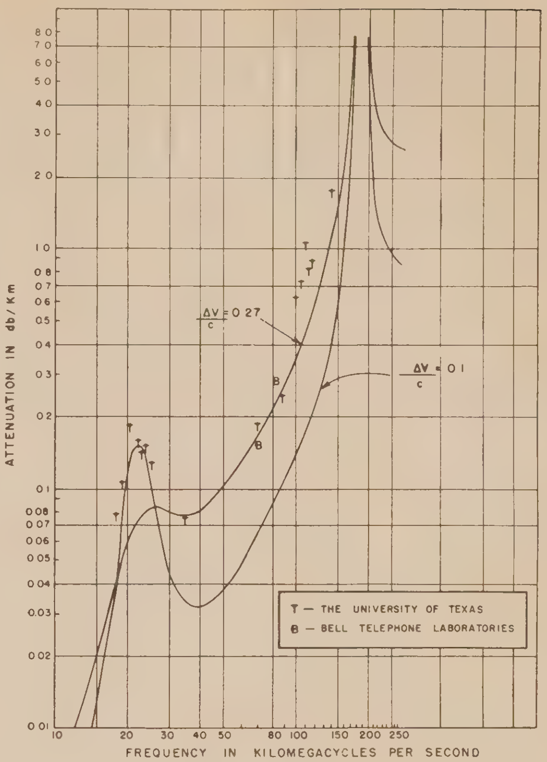

Fig. 2—Water vapor attenuation for 7.5 g/m^3.

In addition to the equipment problems, there are a number of difficulties encountered in the propagation tests that require them to be made with a great deal of care.

The general procedure for making the tests is to observe the signal level on a number of days and to plot this signal strength as a function of water vapor content in the atmosphere. The slope of this line provides the water vapor losses and the ordinate or y-axis intercept provides the oxygen loss.

Inhomogeneity in the water vapor content is known to exist both on small and large scales. In practice, the water vapor concentration is measured at both ends of the path and compared to data available from the U. S. Weather Bureau. The process of time averaging of the measurements and the use of many samples gives a measure of the variation of loss with water vapor concentration which is felt to be quite reliable.

Another annoyance in the measurement is the fact that considerable scintillation in the signal level may occur. The magnitude of these fluctuations is greater than can be explained by variations in the mean water vapor density and therefore must be attributed to refraction effects. The signal chosen as representative of a given sampling period is the mean level.

A third problem in propagation measurements is the presence of precipitation along the path. Care must be taken that the absorption measurements are made at a time when the atmosphere is free of rain or solid particulate matter.

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[9] R. H. Dicke, R. Beringer, R. L. Kyhl, and A. B. Vane, "Atmospheric absorption measurements with a microwave radiometer," *Phys. Rev.*, vol. 70, pp. 340–348; September 1 and 15, 1946.

Summary of Recent Measurements

During recent years, improvements in generators and components have made possible a number of absorption measurements through the actual atmosphere. Such measurements have been made by Bell Telephone Laboratories[10] at wavelengths in the 5- to 6-mm region and at 4.3 and 3.7 mm. Similar measurements have been made by The University of Texas Electrical Engineering Research Laboratory at wavelengths in the range from 1.2 to 1.7 cm, at 8.6 mm, 4.3 mm, 3.35 mm, 2.15 mm, and at a number of wavelengths in the region from 2.5 to 3 mm.[11] The results of all these measurements have been plotted on Figs. 1 and 2 for comparison with the Van Vleck curves.

The points plotted on the log-log curves tend to give the impression of a closer agreement between the measured and theoretical values than actually exists. Some details of the spectrum will be considered later.

From Fig. 1, it is seen that the agreement between the measured and calculated values of absorption for oxygen are reasonably good, but for reasons pointed out later, care should be exercised in extrapolating the data to points very far from the frequencies at which they were measured.

From Fig. 2, it is seen that the water vapor losses are consistently larger than those predicted by Van Vleck for a line breadth constant of 0.1 cm^{-1}. These deviations will be discussed in greater detail in the following sections.

Residual Effect of Submillimeter Water Vapor Lines

In those sections of the microwave spectrum far removed from a water vapor absorption line, the attenuation is primarily controlled by the skirts of the submillimeter lines. This effect is shown in Fig. 3.[12] The line numbers are in the order of increasing frequency. It is noted in the frequency range from 50 to 130 kmc that the first 12 lines make a relatively small contribution to the total absorption and that line numbers 21 through 76 make approximately the same contribution as the first 20 lines.

The curves of Fig. 3 are based on the assumption that the line breadth constant is 0.1 cm^{-1} for all of the lines. Recent evidence has indicated that the line breadth may vary from line to line. Such variations could cause the attenuation curve to rise much more rapidly with frequency than is shown in Fig. 3.

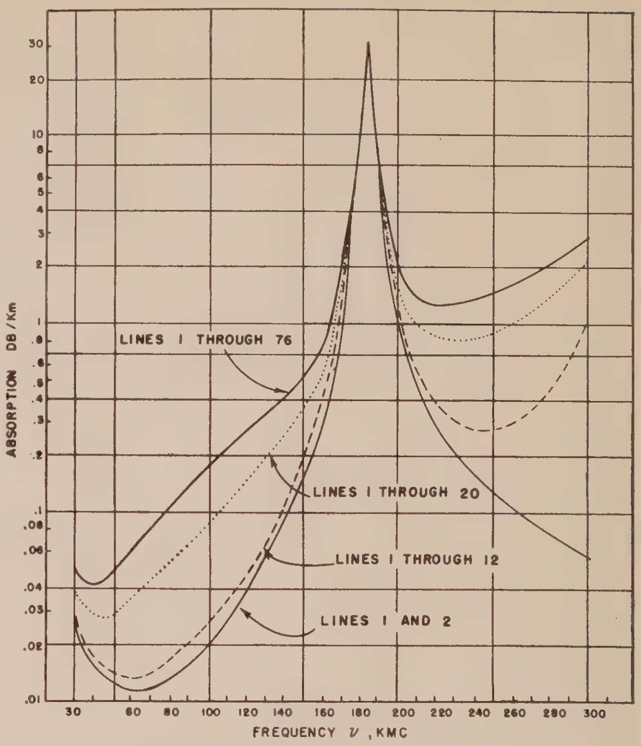

Fig. 3—Calculated water vapor absorption for 7.5 g/m^3 for $\Delta\nu/c=0.1$.

All of the water vapor loss measurements made prior to September 1958 could be approximately accounted for by the expediency of increasing the line breadth constant for the infrared residual lines from 0.1 to 0.27 cm^{-1}.

Recent measurements at The University of Texas, however, have uncovered several anomalies which have thrown out this simple panacea. These newer measurements are described in the following sections.

Measurements Around the 1.35-cm Line

In spite of the fact that the frequency of the 1.35-cm line has been known with precision for some time, quantitative measurements of the magnitude of its absorption through the actual atmosphere are very scarce. For this reason, data were recently taken by the Electrical Engineering Research Laboratory at a number of wavelengths in this region.[13]

These recent data are plotted in Fig. 4 together with the three points reported by Dicke, *et al.*[9] The curve is plotted on a linear basis for one gram of water vapor per cubic meter instead of for the standard atmosphere condition of 7.5 grams. Neither the Van Vleck-Weisskopf curve for the 0.1 cm^{-1} nor for the 0.27 cm^{-1} line breadth constant adequately represents the measured data even in the vicinity of the absorption line.

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[10] "Millimeter Wave Research—Final Report," Bell Telephone Laboratories, New York, N. Y., ONR Contract 687(00), Rept. No. 24261-15; May, 1955.

[11] C. W. Tolbert, A. W. Straiton, and J. H. Douglas, "Studies of 2.15 MM Propagation at an Elevation of 4 KM and the Millimeter Spectrum," Elec. Engrg. Res. Lab., The University of Texas, Austin, Rept. No. 104; November 1, 1958.

[12] W. E. Patterson, "Absorption of Microwaves of Millimeter Wavelength by Atmospheric Water Vapor," Master's Thesis, The University of Texas, Austin; June, 1957.

[13] C. W. Tolbert, A. W. Straiton, and C. O. Britt, "Propagation Studies Between 18.0 and 25.5 KMCS," Elec. Engrg. Res. Lab., The University of Texas, Austin, Rept. No. 110; July 10, 1959.

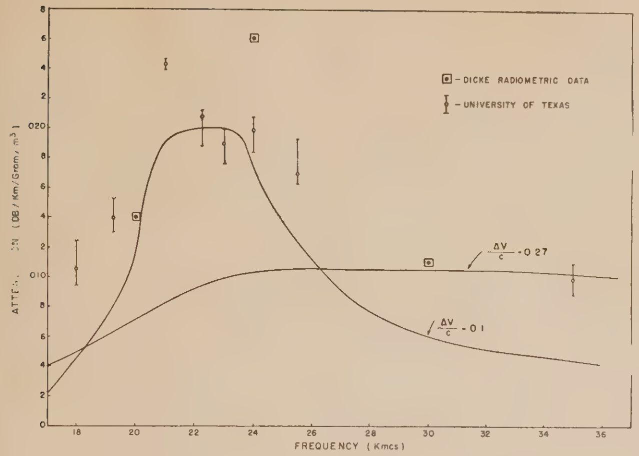

Fig. 4—Water vapor losses in 18.0- to 25.5-kmc spectrum.

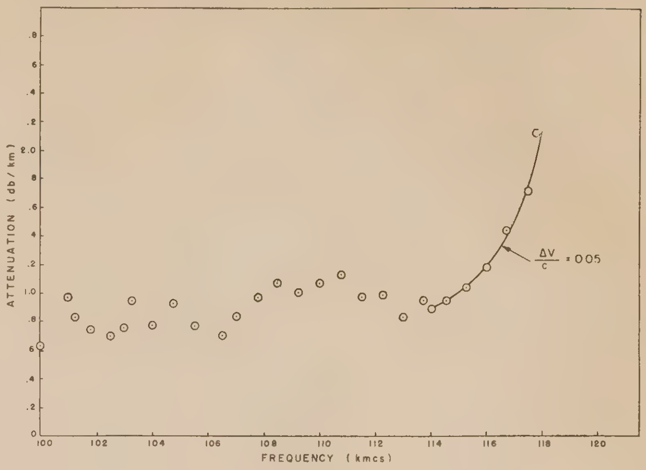

Fig. 5—Attenuation adjusted to standard atmosphere.

Measurements in the 2.5 to 3.0-mm Region

Water Vapor Losses

The University of Texas has recently completed a series of measurements in the wavelength region from 2.5 to 3.0 mm.[14] Sufficient data were taken to obtain the slope of the water vapor line at frequencies of 100, 104.75, 110, 113 and 117.5 kmc, and these five points are shown in Fig. 2. Two anomalies are seen from these data. In the first place, the level of the attenuation is approximately 50 per cent higher than would be indicated by the Van Vleck-Weisskopf equation even for a line breadth constant of 0.27 cm^{-1}. In the second place, the loss at 110 kmc is greater than the loss at the other four frequencies. Although no water vapor line has been predicted at 110 kmc, the increased attenuation at this frequency indicates that such a line may exist.

In addition to the five frequencies at which sufficient data were taken to obtain the water vapor slope, one or more soundings were made at 23 other frequencies in this region. The data were adjusted to the 7.5-grams-per-cubic-meter atmosphere by using a water vapor line slope obtained by interpolating between the values measured at the five frequencies. This may be done with some confidence since the correction applied was a function of the deviation from the standard atmosphere condition. The attenuation adjusted to the standard atmosphere is then shown in Fig. 5.

Oxygen Losses

From the shape of the smooth curve drawn through the higher frequency points, an oxygen absorption line may be fitted. It was found that a line with a resonant frequency of 118.75, a maximum attenuation of 1.7 db/km and a line breadth constant of 0.05 cm^{-1} would give the measured shape.

The line breadth constant at this frequency had been found by Anderson, *et al.*,[15] to be 0.12 cm^{-1} at one atmosphere by laboratory methods. These measurements were made at a temperature of 190° K. A temperature correction to 300° K may be made using the line breadth as inversely proportional to temperature as measured by Hill and Gordy,[16] but the corrected value is still considerably greater than that determined by the propagation measurements.

A similar discrepancy exists around the 5-mm lines. Artman and Gordon[17] determined a line breadth of 0.049 cm^{-1} from laboratory measurements on pure O_2 and O_2-N_2 mixtures. Propagation measurements by Bell Telephone Laboratories and The University of Texas have indicated that the line breadth constant should be nearer 0.02 cm^{-1}.[10,18]

Losses Due to Rare Gases

The data in the region from 100 to 106 kmc were found to be erratic with day-to-day variations which did not correlate with the water vapor density changes. It was therefore felt that these losses were due to some of the rarer gases in the atmosphere such as N_2O, NO_2, SO_2, and O_3, which have resonant frequencies in this general area. These irregular losses were about 0.2 db/km during the measurement period.

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[14] C. W. Tolbert, C. O. Britt, and J. H. Douglas, "Radio Propagation Measurements in the 110 to 118 KMCS Spectrum," Elec. Engrg. Res. Lab., The University of Texas, Austin, Rept. No. 107; April 15, 1959.

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CHANGE IN ATTENUATION WITH PRESSURE

High elevation measurements have been made by The University of Texas at wavelengths of 8.6,[19] 4.3[20] and 2.15[11] mm. These data were taken over paths between mountain peaks in Colorado with elevations from 12,000 to 14,000 feet. Losses due to water vapor were measured at all three wavelengths and the loss due to oxygen was measured at 4.3 mm. The oxygen losses at 8.6 and 2.15 were too small to measure with accuracy. The results of these measurements are shown in Table I.

TABLE I

Wavelength (mm)	Attenuation in db/km	
	Water Vapor (1g/m³)	Oxygen
8.6	0.03	
4.3	0.10	0.22
2.15	0.12	

It is generally assumed that at the resonant frequency the loss for the same concentration of the absorbing gas will be the same regardless of the total pressure of the atmosphere. It is also assumed that the line breadth constant is proportional to the total pressure.

The losses for the higher altitude may be calculated from the Van Vleck-Weisskopf equation by adjusting the line breadth constant for the pressure change starting with line breadth constants at one atmosphere of 0.27 cm^{-1} for water vapor, and 0.02 cm^{-1} for oxygen. Losses calculated on this basis were found to agree reasonably well with the measurements.

In the light of recent anomalies at 1.35 cm and 2.6 mm, however, it would be expected that additional anomalies may be found at high altitudes for other wavelengths. The use of the Van Vleck-Weisskopf equation for higher altitudes should then be limited to the part of the spectrum in which the measurements were made.

DISCUSSION OF DEVIATION OF MEASURED AND PREDICTED ABSORPTION VALUES

In trying to fit the measured points with the Van Vleck-Weisskopf line broadening equation, we find that the use of a single line breadth constant is inadequate. The data may be approximately fitted by introducing a number of line strength and line width constants. In so doing, however, the equation loses much of its simplicity and utility. Some of the relationships that account for the anomalies will be discussed in this section.

Variation of Line Breadth Constant from Line to Line

Benedict and Kaplan[21] point out that there is considerable theoretical and experimental evidence that the line width for the various water vapor lines is different depending on the rotational states involved. With the imposing array of lines which influence millimeter absorption, the absorption-frequency curve could take on a wide variety of shapes. The general effect would be that of having a greater increase in absorption with frequency as the shorter millimeter wavelengths are approached. This has been the general trend in the measured water vapor loss since the ratio of the measured losses to those predicted by Van Vleck vary from three to ten as the frequency goes from 35 to 140 kmc.

Possibility of Unpredicted Lines

The measurements in the 100- to 118-kmc range indicated that a water vapor line occurs at 110 kmc. Although no line has been predicted at this frequency, it would not be surprising if one did occur because of the very complex nature of the water vapor transitions.

An alternate explanation of the water sensitive loss at 110 kmc is that an isotope of H_2O or another of the rarer gases in the atmosphere would vary in concentration in proportion to the water vapor density. There is, however, little theoretical justification of the increased attenuation on this basis.

The effect of some of the rarer gases was observed in the 100- to 106-kmc region where erratic losses of approximately 0.2 db/km were noted. These losses did not vary in proportion to the water vapor concentration, but changed inconsistently from day to day. This is the only region where these effects could be noted, although they might be expected at other frequencies to a lesser amount.

Nonlinearity of Water Vapor Absorption

Water vapor absorption curves as a function of water vapor concentration as measured by The University of Texas and by Bell Telephone Laboratories have shown a tendency to increase faster with water vapor concentration than at a straight line rate. The range of water vapor concentration and the variability of the result have made it difficult to determine the exact deviation from a straight line.

If such nonlinearity does exist, it must be due to the fact that H_2O-H_2O molecular collisions have a much greater effect on line broadening than do H_2O-Air collisions. Becker and Autler estimate a ratio of 5 in the cross section of the H_2O-H_2O collision as compared to the H_2O-Air collision.

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[21] W. S. Benedict and L. D. Kaplan, "Calculation of line width in H_2O-N_2 collisions," *J. Chem. Phys.*, vol. 30, pp. 388–399; February, 1959.

Limitation on Van Vleck-Weisskopf Equation

As pointed out by Van Vleck,[2] an explanation of the deviation of theoretical and experimental determinations of atmospheric absorption could result from limitations of the Van Vleck-Weisskopf equation in the far wings. The validity of this equation when the line widths are in the same order of magnitude as the resonant frequency has been questioned.

On the high-frequency side of the absorption lines, the Van Vleck-Weisskopf equation predicts that the loss will approach a constant. This is known to break down in the infrared region, but the extent of its validity is difficult to predict.

The Van Vleck-Weisskopf equation is based entirely on the broadening of the absorption lines by collisions of the molecules. Other factors which affect line broadening include Doppler broadening, saturation broadening, and radiation broadening. Each of these effects has been discussed by Rogers.[22] Although these other broadening factors are generally considered to be negligible, the possibility of their making a significant contribution should not be overlooked.

CONCLUSIONS

Measurements of the absorption of microwaves by the atmosphere have indicated that theoretical predictions of the losses are not entirely satisfactory. Oxygen losses in the vicinity of the absorption lines may be explained satisfactorily by the proper choices of the line breadth constants. The line breadth constants are, however, lower than those predicted on the basis of nonpropagation-type laboratory measurements.

The measured water vapor losses are consistently higher than predicted. No single line breadth constant will satisfactorily explain the experimental data.

It is felt, therefore, that the extension of experimental absorption data to frequencies, pressures, or mixture ratios considerably different from those used in the measurement programs should be avoided.

APPENDIX

VAN VLECK-WEISSKOPF EQUATION

If a single spectral line, remote from all others, is considered, the attenuation in decibels per kilometer of an incoming electromagnetic wave is given by

$$\gamma = \frac{[10^6 \log_{10} e] 8\pi^2 N p \nu^2 |\mu_{JJ'}|^2 e^{-W_J/kT} S}{3ckTGP}$$

where

γ = absorption coefficient, in decibels per kilometer

c = speed of light $= 2.9979 \times 10^{10}$ cm per second

k = Boltzmann's constant $= 1.3802565 \times 10^{-16}$ erg per degree Kelvin

p = partial vapor pressure of the absorbing gas, in mm of Hg

P = total pressure of the atmosphere, in mm of Hg

T = temperature of the atmosphere, in degrees Kelvin

G = rotational partition function of the absorbing gas (dimensionless)

N = number of molecules per cubic centimeter in the atmosphere $= 9.66 \times 10^{18} \times P/T$

ν = frequency of the incoming electromagnetic wave, in cycles per second

W_J = the energy of the absorbent lower rotational state J, in cm^{-1}

$|\mu_{JJ'}|^2$ = square of the dipole moment matrix element associated with the absorbent rotational transition $J \rightarrow J'$, inclusive of the static dipole moment and weighting factors (dimensionless)

S = the modified structure factor

$$= \frac{\Delta\nu}{(\nu_{JJ'} - \nu)^2 + (\Delta\nu)^2} + \frac{\Delta\nu}{(\nu_{JJ'} + \nu)^2 + (\Delta\nu)^2}$$

where

$\Delta\nu$ = absorption line half-intensity half-width, in cycles per second

$\nu_{JJ'}$ = the center or resonant frequency of the absorbent rotational transition $J \rightarrow J'$, in cycles per second.

As used throughout this paper, the line breadth constant is taken as $\Delta\nu/c$ with the unit of cm^{-1}.

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[22] T. F. Rogers, "Factors Affecting the Width and Shape of Atmospheric Microwave Absorption Lines," AF Cambridge Res. Ctr., Bedford Mass.; October, 1951.

Interaction Impedance Measurements by Propagation Constant Perturbation*

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Summary—**The perturbation in the complex propagation constant of a lossy, nonreciprocal, periodic waveguide produced by the insertion of a rod, which may be cylindrical or periodic, parallel to the waveguide axis is developed. The application to the experimental determination of the interaction impedance and electromagnetic field distribution of waveguides is presented, together with the approximations which are applicable. The perturbation formulas for three particular classes of circuit—lossless, reciprocal, cylindrical circuits; lossy, nonreciprocal, cylindrical circuits; and lossy, nonreciprocal, periodic circuits—of interest for traveling wave tubes and other extended interaction microwave tubes, are derived and the limitations discussed. Explicit interaction impedance relations for these circuits in terms of the phase constant perturbation, caused by a cylindrical or periodic rod, are given.**

I. INTRODUCTION

PERTURBATION techniques have proved to be useful for determining experimentally the electromagnetic field distributions both in resonant microwave structures, such as klystron cavities, and propagating structures, such as slow wave circuits for traveling wave tubes. In particular, the determination of the interaction impedance $Z=E^2/2\beta^2S$ of traveling wave tube circuits is readily accomplished using perturbation measurements (S is the total power on the circuit, β is the propagation constant, and E is the peak longitudinal electric field strength at the position where the electron beam will be located). The techniques for using a resonated section of the circuit (resonated using shorting plates) and obtaining the interaction impedance from a measurement of the change in resonant frequency of the section caused by the insertion of a small dielectric or metallic bead are well known.[1,2] One formulation of the relationship between the perturbing bead parameters, the change in the resonant frequency, and the electromagnetic fields in the resonant section which has a close relation to the treatment presented here has been given by Casimir.[3] There have been many others as well.[4–7] Of course, the converse procedure of using the change in resonant frequency and Q of a standard cavity to investigate the dielectric and magnetic parameters of small samples of material introduced into the cavity is also well known.

For stability reasons, most traveling wave tube circuits are intentionally made somewhat lossy. These lossy circuits are not amenable to the resonant section technique because of their low Q and the resulting difficulty in measuring the resonant frequency accurately. In addition, there has been some interest in recent years in using ferrite loaded circuits to obtain nonreciprocal attenuation properties, and these circuits are not readily adapted to conventional resonant section perturbation techniques because of the nonreciprocity. Therefore, measurement techniques which are applicable to propagating circuits and use the perturbation of the propagation constant by a bead or rod to determine the electromagnetic field pattern and the interaction impedance are necessary. Of course, the propagation constant perturbation and the resonant frequency perturbation measurements are complementary and closely related. For example, measurements on a propagating circuit might be made by determining the change in applied frequency necessary to hold the propagation constant unchanged when a perturbing object is inserted. However, attention will be confined here to constant frequency measurements in which the propagation constant is perturbed.

Measurements of the interaction impedance of slow wave circuits using the technique of the perturbation of the propagation constant are, of course, not new.[2] Kino[8] has given a derivation of the propagation constant perturbation caused by a dielectric or metallic rod in a lossy, periodic, reciprocal system using normal mode techniques. Lagerstrom[9] has considered lossless, peri-

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* Original manuscript received by the IRE, August 14, 1959; revised manuscript received December 21, 1959.

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[9] R. P. Lagerstrom, "Interaction Impedance Measurements by Perturbation of Traveling Waves," Stanford Electronics Labs., Stanford University, Stanford, Calif., TR No. 7; February 11, 1957.

odic, reciprocal systems and analyzed in some detail the effects of perturbing rod size as well as periodic rods. The treatment here will be applicable to lossy, periodic, nonreciprocal structures and is based on a field theory approach which gives a direct derivation of an exact relationship and facilitates the evaluation of approximations convenient for measurements. The derivation is basically analogous to Casimir's[3] treatment of lossless resonant cavities, but is a generalization and adaptation applicable to lossy, periodic, nonreciprocal, propagating structures. Several related treatments are also of interest. Goubau[10] has discussed the perturbation of the input impedance of an electromagnetic system caused by the insertion of a test body, while Redfield[11] has considered the perturbation of the admittance matrix of an electrodynamic system. Auld[12] has developed a related perturbation theorem for the scattering matrix at a junction.

II. Derivation of Basic Equations

Consider a waveguide of arbitrary cross section which is periodic with period L in the direction of propagation z and which has a single frequency wave propagating in the z direction. It is assumed that only one of the possible modes of the structure is excited. By Floquet's theorem, the fields in the waveguide may be written as

$$\begin{aligned} \boldsymbol{E}_i(x, y, z, t) &= \boldsymbol{E}_0(x, y, z)e^{j\omega t-\Gamma_0 z} \\ &= \sum_n \boldsymbol{E}_{0n}(x, y)e^{j\omega t-(\Gamma_0+j2\pi n/L)z}, \end{aligned} \tag{1a}$$

$$\begin{aligned} \boldsymbol{H}_i(x, y, z, t) &= \boldsymbol{H}_0(x, y, z)e^{j\omega t-\Gamma_0 z} \\ &= \sum_n \boldsymbol{H}_{0n}(x, y)e^{j\omega t-(\Gamma_0+j2\pi n/L)z}, \end{aligned} \tag{1b}$$

where the propagation constant $\Gamma_0=\alpha_0+j\beta_0$ is complex for a lossy waveguide. Note that $\boldsymbol{E}_0$ and $\boldsymbol{H}_0$ are periodic in z with period L, while the space harmonic field amplitudes $\boldsymbol{E}_{0n}$ and $\boldsymbol{H}_{0n}$ are independent of z. If the waveguide is cylindrical rather than periodic, all the $\boldsymbol{E}_{0n}$ and $\boldsymbol{H}_{0n}$ for $n\neq 0$ are zero.

Now let a rod be inserted into the waveguide parallel to, but not necessarily coinciding with, the z axis. The "rod" may be either uniform in cross section, or be periodic in z with period L, *e.g.*, a series of beads spaced at intervals equal to L. Hereafter, the term "rod" will refer to either of these configurations unless explicitly stated to the contrary. The final fields after the insertion of the rod will be

$$\begin{aligned} \boldsymbol{E}_f(x, y, z, t) &= [\boldsymbol{E}_0(x, y, z) + \boldsymbol{E}_1(x, y, z)]e^{j\omega t-(\Gamma_0+\Gamma_1)z} \\ &= \sum_n [\boldsymbol{E}_{0n}(x, y) + \boldsymbol{E}_{1n}(x, y)]e^{j\omega t-(\Gamma_0+\Gamma_1+j2\pi n/L)z} \end{aligned} \tag{2a}$$

$$\begin{aligned} \boldsymbol{H}_f(x, y, z, t) &= [\boldsymbol{H}_0(x, y, z) + \boldsymbol{H}_1(x, y, z)]e^{j\omega t-(\Gamma_0+\Gamma_1)z} \\ &= \sum_n [\boldsymbol{H}_{0n}(x, y) + \boldsymbol{H}_{1n}(x, y)]e^{j\omega t-(\Gamma_0+\Gamma_1+j2\pi n/L)z}. \end{aligned} \tag{2b}$$

It is assumed that only a single mode of the perturbed system has been excited, with a propagation constant $\Gamma_0+\Gamma_1=\alpha_0+\alpha_1+j(\beta_0+\beta_1)$, and that this mode has a field distribution which is roughly similar to that of the original mode.

From Maxwell's curl equations,

$$\nabla \times \boldsymbol{E}_0 - \Gamma_0(\boldsymbol{k} \times \boldsymbol{E}_0) = -j\omega \boldsymbol{B}_0, \tag{3a}$$

$$\nabla \times \boldsymbol{H}_0 - \Gamma_0(\boldsymbol{k} \times \boldsymbol{H}_0) = j\omega \boldsymbol{D}_0, \tag{3b}$$

$$\begin{aligned} \nabla \times \boldsymbol{E}_1 - (\Gamma_0 + \Gamma_1)(\boldsymbol{k} + \boldsymbol{E}_1) - \Gamma_1(\boldsymbol{k} \times \boldsymbol{E}_0) \\ = -j\omega \boldsymbol{B}_1, \end{aligned} \tag{3c}$$

$$\nabla \times \boldsymbol{H}_1 - (\Gamma_0 + \Gamma_1)(\boldsymbol{k} \times \boldsymbol{H}_1) - \Gamma_1(\boldsymbol{k} \times \boldsymbol{H}_0) = j\omega \boldsymbol{D}_1, \tag{3d}$$

where $\boldsymbol{k}$ is a unit vector in the z direction. By multiplying (3c) and (3d), respectively, by $\boldsymbol{H}_0^*$ and $\boldsymbol{E}_0^*$ (* denotes complex conjugate), combining, and using a vector identity,

$$\begin{aligned} &\boldsymbol{E}_0^* \cdot \nabla \times \boldsymbol{H}_1 - \boldsymbol{H}_0^* \cdot \nabla \times \boldsymbol{E}_1 = -\nabla \cdot (\boldsymbol{E}_0^* \times \boldsymbol{H}_1 + \boldsymbol{E}_1 \times \boldsymbol{H}_0^*) \\ &\quad - \boldsymbol{E}_1 \cdot \nabla \times \boldsymbol{H}_0^* + \boldsymbol{H}_1 \cdot \nabla \times \boldsymbol{E}_0^* \\ &= -\Gamma_1 \boldsymbol{k} \cdot (\boldsymbol{E}_0 \times \boldsymbol{H}_0^* + \boldsymbol{E}_0^* \times \boldsymbol{H}_0) - (\Gamma_0 + \Gamma_1)\boldsymbol{k} \\ &\quad \cdot (\boldsymbol{E}_1 \times \boldsymbol{H}_0^* + \boldsymbol{E}_0^* \times \boldsymbol{H}_1) + j\omega(\boldsymbol{E}_0^* \cdot \boldsymbol{D}_1 + \boldsymbol{H}_0^* \cdot \boldsymbol{B}_1). \end{aligned} \tag{4}$$

After multiplication by exp $(-2\alpha_0 z)$ and utilization of a vector identity, integration over one period of the waveguide, and the application of Gauss' theorem, there results

$$\begin{aligned} &\Gamma_1 \iiint_V \boldsymbol{k} \cdot (\boldsymbol{E}_0 \times \boldsymbol{H}_0^* + \boldsymbol{E}_0^* \times \boldsymbol{H}_0)e^{-2\alpha_0 z}dv \\ &\quad + \Gamma_1 \iiint_V \boldsymbol{k} \cdot (\boldsymbol{E}_0^* \times \boldsymbol{H}_1 + \boldsymbol{E}_1 \times \boldsymbol{H}_0^*)e^{-2\alpha_0 z}dv \\ &= j\omega \iiint_V (\boldsymbol{E}_0^* \cdot \boldsymbol{D}_1 - \boldsymbol{D}_0^* \cdot \boldsymbol{E}_1 + \boldsymbol{H}_0^* \\ &\qquad \cdot \boldsymbol{B}_1 - \boldsymbol{B}_0^* \cdot \boldsymbol{H}_1)e^{-2\alpha_0 z}dv \\ &\quad + \iint_A \boldsymbol{n} \cdot (\boldsymbol{E}_0^* \times \boldsymbol{H}_1 + \boldsymbol{E}_1 \times \boldsymbol{H}_0^*)e^{-2\alpha_0 z}da. \end{aligned} \tag{5}$$

Here V denotes a volume corresponding to one period of the waveguide, A denotes the surface area enclosing this volume, and $\boldsymbol{n}$ is a unit vector normal to this surface, directed outward. Any currents present in materials with finite conductivity are included in the electric displacement vectors $\boldsymbol{D}_0$ and $\boldsymbol{D}_1$ by having the imaginary part of the dielectric constant include the conductivity as well as the dielectric loss term.

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We note that $\boldsymbol{D}_0 = \hat{\epsilon}_i \cdot \hat{\boldsymbol{E}}_0$ and $\boldsymbol{B}_0 = \hat{\mu}_i \cdot \boldsymbol{H}_0$, where $\hat{\epsilon}_i$ and $\hat{\mu}_i$ are the dielectric constant and permeability of the material in the waveguide prior to the insertion of the perturbing rod. These, in general, will be functions of position within the waveguide and complex to account for losses. The circumflex indicates that these may be tensor quantities, as is, for example, the permeability of a ferrite material. Also, in all regions external to the perturbing rod, $\boldsymbol{D}_1 = \hat{\epsilon}_i \cdot \boldsymbol{E}_1$ and $\boldsymbol{B}_1 = \hat{\mu}_i \cdot \boldsymbol{H}_1$. Since it is assumed that the rod is inserted only into regions which were previously empty, (5) may be rewritten as

$$\begin{aligned}
\Gamma_1 \iiint_V & \boldsymbol{k} \cdot (\boldsymbol{E}_0 \times \boldsymbol{H}_0^* + \boldsymbol{E}_0^* \times \boldsymbol{H}_0) e^{-2\alpha_0 z} dv \\
& + \Gamma_1 \iiint_V \boldsymbol{k} \cdot (\boldsymbol{E}_0^* \times \boldsymbol{H}_1 + \boldsymbol{E}_1 \times \boldsymbol{H}_0^*) e^{-2\alpha_0 z} dv \\
= j\omega & \iiint_{\delta V} (\epsilon_0 \boldsymbol{E}_0^* \cdot \boldsymbol{P} + \mu_0 \boldsymbol{H}_0^* \cdot \boldsymbol{M}) e^{-2\alpha_0 z} dv \\
& + j\omega \iiint_{V-\delta V} [\boldsymbol{E}_0^* \cdot (\hat{\epsilon}_i \boldsymbol{E}_1) - \boldsymbol{E}_1 \cdot (\hat{\epsilon}_i \cdot \boldsymbol{E}_0)^* + \boldsymbol{H}_0^* \\
& \qquad \cdot (\hat{\mu}_i \cdot \boldsymbol{H}_1) - \boldsymbol{H}_1 \cdot (\hat{\mu}_i \cdot \boldsymbol{H}_0)^*] e^{-2\alpha_0 z} dv \\
& + \iint_A \boldsymbol{n} \cdot (\boldsymbol{E}_0^* \times \boldsymbol{H}_1 + \boldsymbol{E}_1 \times \boldsymbol{H}_0^*) e^{-2\alpha_0 z} da, \qquad (6)
\end{aligned}$$

where $\boldsymbol{P} = \boldsymbol{D}_1/\epsilon_0 - \boldsymbol{E}_1$ and $\boldsymbol{M} = \boldsymbol{B}_1/\mu_0 - \boldsymbol{H}_1$ are the polarization and magnetization of the rod. δV denotes the volume of one period of the rod and $V - \delta V$ denotes the volume of one period of the waveguide exclusive of the rod volume. Eq. (6) is an exact expression relating the change in the propagation constant to the fields and the rod parameters. The first integral on the left is recognized to be four times the time average power in the z direction of the original unperturbed circuit integrated over a length in the z direction equal to one period of the structure. Thus, the first term on the left can be put in the form,

$$\begin{aligned}
\Gamma_1 \iiint_V & \boldsymbol{k} \cdot (\boldsymbol{E}_0 \times \boldsymbol{H}_0^* + \boldsymbol{E}_0^* \times \boldsymbol{H}_0) e^{-2\alpha_0 z} dv \\
& = 4\Gamma_1 \int_z^{z+L} S_0(z) dz, \qquad (7)
\end{aligned}$$

where $S_0(z)$ represents the time average power in the z direction. $S_0(z)$ is, of course, real so that by taking the real and imaginary parts of (6), expressions for α_1 and β_1 can be obtained.

The integrals in (6) are taken over one complete period of the structure; this is precisely defined for the z direction, but is somewhat vague for the transverse directions. For structures with enclosing, perfectly conducting walls, it suffices to integrate over the volume enclosed by the walls. In this case, of course, all the fields external to the region enclosed by the walls are zero. For open boundary structures, *e.g.*, an unshielded helix, the fields exist out to infinity, and one must integrate out to infinity in the transverse directions. For structures with imperfectly conducting walls, the fields will again extend out to infinity in the transverse directions. Those fields external to the walls are clearly negligible when the waveguide walls are made of the usual metals. However, to cover all possible cases here, we will integrate out to infinity in the transverse directions, but we recognize that for many important cases the contribution from the fields external to the waveguide walls will be completely negligible. By integrating out to infinity, the surface integral of (6) may be simplified because the fields will go to zero at infinity for structures that propagate a mode carrying finite power in the z direction. Thus, in all cases there will be a contribution to the surface integral possible only over planes that are normal to the z axis.

Using this simplification, (6) may be written as

$$\begin{aligned}
4\Gamma_1 & \int_z^{z+L} S_0(z) dz \\
& + \Gamma_1 \iiint_V \boldsymbol{k} \cdot (\boldsymbol{E}_0^* \times \boldsymbol{H}_1 + \boldsymbol{E}_1 \times \boldsymbol{H}_0^*) e^{-2\alpha_0 z} dv \\
= j\omega & \iiint_{\delta V} (\epsilon_0 \boldsymbol{E}_0^* \cdot \boldsymbol{P} + \mu_0 \boldsymbol{H}_0^* \cdot \boldsymbol{M}) e^{-2\alpha_0 z} dv \\
& + j\omega \iiint_{V-\delta V} [\boldsymbol{E}_0^* \cdot (\hat{\epsilon}_i \cdot \boldsymbol{E}_1) - \boldsymbol{E}_1 (\hat{\epsilon}_1 \cdot \boldsymbol{E}_0)^* + \boldsymbol{H}_0^* \\
& \qquad \cdot (\hat{\mu}_i \cdot \boldsymbol{H}_1) - \boldsymbol{H}_1 \cdot (\hat{\mu}_i \cdot \boldsymbol{H}_0)^*] e^{-2\alpha_0 z} dv \\
& - (1 - e^{-2\alpha_0 L}) e^{-2\alpha_0 z} \iint_{A_c} \boldsymbol{k} \\
& \qquad \cdot (E_0^* \times H_1 + E_1 \times H_0^*) da. \qquad (8)
\end{aligned}$$

Here A_c represents the waveguide cross section at $z = z$ or $z = z + L$ (the cross section at these two points is the same because of the periodicity). As noted above, A_c may extend out to infinity. It should be observed that the equality in (8) is independent of the value of z chosen.

III. APPLICATION TO INTERACTION IMPEDANCE MEASUREMENTS

Eq. (8) is the basic equation with which we will deal. As it stands, it is too cumbersome to be useful in practice, but in many cases of interest, approximations can be made which render it useful for the experimental measurement of the interaction impedance. In order to determine what approximations are valid and their implications, several special cases will be examined in some detail.

A. Lossless, Reciprocal, Cylindrical Waveguides

In this case $\alpha_0 = 0$, the dielectric constant and permeability are real scalars, and since only the fundamental space harmonic fields exist, each of the integrands in (8) has the same z dependence, exp $(-2\alpha_0 z)$, and the integration over z may be omitted. β_1 is found by adding (8) to its complex conjugate.

$$\beta_1 = \omega \frac{\iint_{\delta A} \left[\epsilon_0(\boldsymbol{E}_0^* \cdot \boldsymbol{P} + \boldsymbol{E}_0 \cdot \boldsymbol{P}^*) + \mu_0(\boldsymbol{H}_0^* \cdot \boldsymbol{M} + \boldsymbol{H}_0 \cdot \boldsymbol{M}^*)\right] da}{8S_0 + \iint_{A_c} \boldsymbol{k} \cdot (\boldsymbol{E}_0^* \times \boldsymbol{H}_1 + \boldsymbol{E}_0 \times \boldsymbol{H}_1^* + \boldsymbol{E}_1 \times \boldsymbol{H}_0^* + \boldsymbol{E}_1^* \times \boldsymbol{H}_0) da}. \tag{9}$$

δA denotes the cross section of the perturbing rod which is cylindrical.

It will be observed that, so far, no restrictions have been placed on the constancy of the power before and after the rod insertion. Naturally, β_1 is independent of the power level, but the individual integrals in (9) will vary with the power. For convenience, we will arbitrarily demand that the power level be kept constant throughout the measurements. That is,

$$S_0 = S_0 + S_1, \tag{10a}$$

$$S_1 = 0, \tag{10b}$$

where S_1 is the change in power,

$$S_1 = \frac{1}{4} \iint_{A_c} \boldsymbol{k} \cdot (E_0 \times H_1^* + E_0^* \times H_1 + E_1 \times H_0^* + E_1^* \times H_0 + E_1 \times H_1^* + E_1^* \times H_1) e^{-2\alpha_0 z} da. \tag{11}$$

Therefore,

$$\iint_{A_c} \boldsymbol{k} \cdot (\boldsymbol{E}_1 \times \boldsymbol{H}_1^* + \boldsymbol{E}_1^* \times \boldsymbol{H}_1) e^{-2\alpha_0 z} da = -\iint_{A_c} \boldsymbol{k} \cdot (\boldsymbol{E}_0 \times \boldsymbol{H}_1^* + \boldsymbol{E}_0^* \times \boldsymbol{H}_1 + \boldsymbol{E}_1 \times \boldsymbol{H}_0^* + \boldsymbol{E}_1^* \times \boldsymbol{H}_0) e^{-2\alpha_0 z} da. \tag{12}$$

It should be noted that (12) is general and holds for lossy, nonreciprocal, periodic waveguides as long as the power is held constant.

$$\beta_1 = \omega \frac{\iint_{\delta A} \left[\epsilon_0(\boldsymbol{E}_0^* \cdot \boldsymbol{P} + \boldsymbol{E}_0 \cdot \boldsymbol{P}^*) + \mu_0(\boldsymbol{H}_0^* \cdot \boldsymbol{M} + \boldsymbol{H}_0 \cdot \boldsymbol{M}^*)\right] da}{8S_0 - \iint_{A_c} \boldsymbol{k} \cdot (E_1 \times H_1^* + E_1^* \times H_1) da}. \tag{13}$$

This expression, which is exact, can be simplified by making two assumptions about the perturbing rod's parameters. 1) The rod's cross-sectional dimensions are small compared to the waveguide dimensions and the wavelength of the propagating wave. 2) The combined effect of the perturbing rod's dielectric constant, permeability, and cross-sectional area is such that, external to the rod, the perturbation of the fields is small. These assumptions imply that $|\beta_1| \ll \beta_0$.

As a consequence of these assumptions, we can relate the components of the polarization and magnetization in the rod to the components of the initial electric and magnetic fields at the rod location through the use of the effective electric and magnetic susceptibilities χ_e and χ_m of the rod material and the effective depolarizing and demagnetizing factors for the rod geometry. This use of geometrical factors implies that the rod cross section is at least elliptical. The polarization and magnetization components are given by $P_x = \chi_e E_{0x}/(1 + N_{ex}\chi_e)$, $M_x = \chi_m H_{0x}/(1 + N_{mx}\chi_m)$, etc., where N_{ex}, N_{mx} are the effective depolarizing and demagnetizing factors for fields in the x direction. With the assumptions above, N_e and N_m are given by the static values for an elliptic body. When several field components are simultaneously present, then each will separately produce a perturbation whose magnitude depends on the N value for the particular direction. The geometry of the rod may be adjusted to emphasize or minimize the perturbation caused by the field in any particular direction by controlling the N values.

The assumption that the fields in the rod are essentially uniform over the cross section means that the integrand in the numerator of (13) is independent of position in the rod. Finally, by assumption 2), it is seen that the second term in the denominator will be small compared to $4S_0$. Letting the subscript r refer to the value of the fields at the rod location, the change in the propagation constant is approximately given by

$$\beta_1 \cong \omega \delta A \frac{\left[\frac{\epsilon_0 \chi_e}{1 + N_e \chi_e} |E_0|_r^2 + \frac{\mu_0 \chi_m}{1 + N_m \chi_m} |H_0|_r^2\right]}{4S_0}, \tag{14}$$

which is the customary expression.

It has also been tacitly assumed that the rod itself is lossless. If the rod were lossy, then one or both of χ_e, χ_m would be complex and (14) would change slightly. Also, α_1 could be written down by subtracting (8) from its complex conjugate. For cases where the fields are not uniform over the rod cross section so that using the static values of N_e and N_m is not justified, correction factors may be obtained by examining the integral in the numerator of (9) for particular cases (Lagerstrom[9] has discussed correction factors in some detail).

Eq. (14) indicates that, by using dielectric rods for which $\chi_m = 0$, or metallic rods so shaped as to emphasize the effective χ_e relative to the effective χ_m, the interaction impedance can be obtained by measuring β_0, β_1, and the rod parameters.

$$Z = \frac{|E_0|_r^2}{2\beta_0^2 S_0} \cong \frac{2\beta_1}{\omega\beta_0^2 \delta A \dfrac{\epsilon_0 \chi_e}{1 + N_e \chi_e}}. \tag{15}$$

Eq. (15) also holds for lossless, reciprocal, periodic waveguides if the rod is cylindrical and inserted at a location where only one of the space harmonic fields has an appreciable magnitude. In this case, the impedance is that of the particular space harmonic, and E_0 should be replaced by E_{0n} in (15).

B. Lossy, Nonreciprocal, Cylindrical Waveguides

Again, since only the fundamental space harmonic can exist, all of the integrands of (8) have the same z dependence so that integration over z may be omitted. Eq. (8) now reduces to

$$\begin{aligned} 4\Gamma_1 S_0(z) &+ \Gamma_1 \iint_{A_c} \boldsymbol{k}\cdot(\boldsymbol{E}_0^* \times \boldsymbol{H}_1 + \boldsymbol{E}_1 \times \boldsymbol{H}_0^*) e^{-2\alpha_0 z} da \\ &= j\omega \iint_{\delta A} (\epsilon_0 \boldsymbol{E}_0^* \cdot \boldsymbol{P} + \mu_0 \boldsymbol{H}_0^* \cdot \boldsymbol{M}) e^{-2\alpha_0 z} da \\ &\quad + j\omega \iint_{Ac-\delta A} [\boldsymbol{E}_0^* \cdot (\hat{\epsilon}_i \cdot \boldsymbol{E}_1) - \boldsymbol{E}_1 \cdot (\hat{\epsilon}_i \cdot \boldsymbol{E}_0)^* \\ &\qquad + \boldsymbol{H}_0^* \cdot (\hat{\mu}_i \cdot \boldsymbol{H}_1) - \boldsymbol{H}_1 \cdot (\hat{\mu}_i \cdot \boldsymbol{H}_0)^*] e^{-2\alpha_0 z} da. \end{aligned} \tag{16}$$

Inasmuch as the most important sources of nonreciprocal effects at microwave frequencies are ferrite materials, $\hat{\mu}_i$ will be taken as a tensor but $\hat{\epsilon}_i$ will be regarded as a scalar. Therefore, in the last integral of (16),

$$\boldsymbol{E}_0^* \cdot (\hat{\epsilon}_i \cdot \boldsymbol{E}_1) - \boldsymbol{E}_1 \cdot (\hat{\epsilon}_i \cdot \boldsymbol{E}_0)^* = \boldsymbol{E}_0^* \cdot \boldsymbol{E}_1 \, (\epsilon_i - \epsilon_i^*). \tag{17}$$

$\boldsymbol{E}_0^* \cdot \boldsymbol{E}_1$ will be real in the lossless case and not far different for the usual range of traveling wave tube attenuation. $(\epsilon_i - \epsilon_i^*)$ will be nonzero only in regions where there is lossy dielectric material or material with finite conductivity. Since $(\epsilon_i - \epsilon_i^*)$ is pure imaginary, (17) will be nearly pure imaginary. Therefore, its contribution to β_1 will be negligible, although the contribution to α_1 may be significant.

The situation regarding the magnetic field terms of the last integral in (16) is somewhat more complex. In general, there can be a contribution to β_1 from these terms even in the lossless case because of the off-diagonal elements of the permeability tensor. Thus, it is not clear in the general case what the relative magnitude of the contribution to β_1 from these terms will be. However, there is one important class of ferrite loaded waveguide structures about which more may be said. If the magnetic fields within the ferrite are circularly polarized in a plane perpendicular to the direction of the applied dc magnetic field, then the effective permeability tensor becomes diagonal.[13] If we assume that the perturbing rod is so located that the perturbed field is also circularly polarized in the ferrite, then

$$\boldsymbol{H}_0^* \cdot (\hat{\mu}_i \cdot \boldsymbol{H}_1) - \boldsymbol{H}_1 \cdot (\hat{\mu}_i \cdot \boldsymbol{H}_0)^* = \boldsymbol{H}_0^* \cdot \boldsymbol{H}_1 (\mu_{cp} - \mu_{cp}^*), \tag{18}$$

where μ_{cp} represents the effective permeability in this case. This is the same form that occurred in (17) so that the remarks made there apply here as well. It is reasonable to assume that, in the more practical cases where the fields are not exactly circularly polarized but are nearly so in the ferrite, the contribution to β_1 of the term in (18) will still be negligible. This case, where the ferrite is located in a circularly polarized microwave field, is the one of most practical importance and most widespread use in traveling wave tubes.

In the more general situation of arbitrary polarization of the fields in the ferrite, the contribution to β_1 of the tensor permeability terms will be small if the perturbation is such that the change in the field energy stored within the ferrite associated with the off-diagonal permeability elements is small compared to the total change in field energy stored in the whole structure.

Assuming, then, that the above discussion is applicable, and introducing the two assumptions made in Section III, *A*,

$$\beta_1 \cong \frac{\omega\delta A e^{-2\alpha_0 z}}{4S_0(z)} \left\{ \frac{\epsilon_0}{2} \left[\left(\frac{\chi_e}{1 + N_e\chi_e} \right) + \left(\frac{\chi_e}{1 + N_e\chi_e} \right)^* \right] |E_0|_r^2 + \frac{\mu_0}{2} \left[\left(\frac{\chi_m}{1 + N_m\chi_m} \right) + \left(\frac{\chi_m}{1 + N_m\chi_m} \right)^* \right] |H_0|_r^2 \right\}, \tag{19a}$$

$$\begin{aligned} \alpha_1 \cong \frac{\omega\delta A e^{-2\alpha_0 z}}{4S_0(z)} &\left\{ \frac{\epsilon_0}{2} \left[\left(\frac{\chi_e}{1 + N_e\chi_e} \right) - \left(\frac{\chi_e}{1 + N_e\chi_e} \right)^* \right] |E_0|_r^2 + \frac{\mu_0}{2} \left[\left(\frac{\chi_m}{1 + N_m\chi_m} \right) - \left(\frac{\chi_m}{1 + N_m\chi_m} \right)^* \right] |H_0|_r^2 \right\} \\ &+ \frac{j\omega e^{-2\alpha_0 z}}{8S_0(z)} \iint_{A_c-\delta A} [(\epsilon_i - \epsilon_i^*)(\boldsymbol{E}_0^* \cdot \boldsymbol{E}_1 + \boldsymbol{E}_0 \cdot \boldsymbol{E}_1^*) + (\mu_{cp} - \mu_{cp}^*)(\boldsymbol{H}_0^* \cdot \boldsymbol{H}_1 + \boldsymbol{H}_0 \cdot \boldsymbol{H}_1^*)] da. \end{aligned} \tag{19b}$$

The expression for β_1 is in a form similar to (14) so that the remarks made there about the application to interaction impedance measurements apply here as well.

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[13] D. Polder, "On the theory of ferromagnetic resonance," *Phil. Mag.*, vol. 40, pp. 99–115; January, 1949.

$$Z \cong \frac{4\beta_1}{\omega\beta_0{}^2\delta A\epsilon_0\left[\left(\dfrac{\chi_e}{1+N_e\chi_e}\right)+\left(\dfrac{\chi_e}{1+N_e\chi_e}\right)^*\right]}. \qquad (20)$$

The expression for α_1 reveals several interesting points. Under certain circumstances, a lossy rod may be used to make interaction impedance measurements by noting the change in attenuation of the structure when the rod is inserted. For this to be possible, the effective value of

$$\left(\frac{\chi_e}{1+N_e\chi_e}\right)-\left(\frac{\chi_e}{1+N_e\chi_e}\right)^*$$

relative to

$$\left(\frac{\chi_m}{1+N_m\chi_m}\right)-\left(\frac{\chi_m}{1+N_m\chi_m}\right)^*$$

must be large and the structure must either be originally low-loss and reciprocal, or the rod geometry and placement be such that the contribution to α_1 from the last integral of (19b) be negligible. Under these conditions,

$$Z \cong \frac{4\alpha_1}{j\omega\delta A\beta_0{}^2\epsilon_0\left[\left(\dfrac{\chi_e}{1+N_e\chi_e}\right)-\left(\dfrac{\chi_e}{1+N_e\chi_e}\right)^*\right]}. \qquad (21)$$

α_1 may be either positive or negative in general, depending on the field distribution relative to the lossy regions before and after inserting the rod. For example, if a lossless, high dielectric constant rod is inserted along the center of a waveguide with lossy walls, then α_1 will be negative because the rod causes an increased percentage of the total field energy to be concentrated in the lossless region. If this same rod were inserted along one of the waveguide walls, then α_1 might be positive since the percentage of the total field energy in the lossy region might increase.

C. Lossy, Nonreciprocal, Periodic Waveguides

For periodic structures it is necessary to retain the integration in z over a complete period of the waveguide since $\boldsymbol{E}_0$, $\boldsymbol{E}_1$, $\boldsymbol{H}_0$, $\boldsymbol{H}_1$, etc., are periodic functions of z. $S_0(z)$ will no longer vary as $\exp(-2\alpha_0 z)$ although it is still true that $S_0(z+L)$ differs from $S_0(z)$ by $\exp(-2\alpha_0 L)$. The z dependence of $S_0(z)$ will depend on the distribution of the lossy material in the waveguide. The discussion in Section III, *B* relative to the contribution of the dielectric loss terms and the tensor permeability to β_1 and α_1 applies to the periodic structure as well. Therefore, utilizing this and the assumptions made in Section III, *A*, (8) may be reduced to the following pair of equations for β_1 and α_1,

$$\beta_1 \cong \frac{\omega\delta A\displaystyle\int_z^{z+L}\left\{\frac{\epsilon_0}{2}\left[\left(\frac{\chi_e}{1+N_e\chi_e}\right)+\left(\frac{\chi_e}{1+N_e\chi_e}\right)^*\right]\boldsymbol{E}_0\cdot\boldsymbol{E}_0{}^*+\frac{\mu_0}{2}\left[\left(\frac{\chi_m}{1+N_m\chi_m}\right)+\left(\frac{\chi_m}{1+N_m\chi_m}\right)^*\right]\boldsymbol{H}_0\cdot\boldsymbol{H}_0{}^*\right\}e^{-2\alpha_0 z}dz}{4\displaystyle\int_z^{z+L}S_0(z)dz}, \qquad (22a)$$

$$\alpha_1 \cong \frac{j\omega\delta A\displaystyle\int_z^{z+L}\left\{\frac{\epsilon_0}{2}\left[\left(\frac{\chi_e}{1+N_e\chi_e}\right)-\left(\frac{\chi_e}{1+N_e\chi_e}\right)^*\right]\boldsymbol{E}_0\cdot\boldsymbol{E}_0{}^*+\frac{\mu_0}{2}\left[\left(\frac{\chi_m}{1+N_m\chi_m}\right)-\left(\frac{\chi_m}{1+N_m\chi_m}\right)^*\right]\boldsymbol{H}_0\cdot\boldsymbol{H}_0{}^*\right\}e^{-2\alpha_0 z}dz}{4\displaystyle\int_z^{z+L}S_0(z)dz}$$

$$+\frac{j\omega\displaystyle\int_z^{z+L}\iint_{A_c-\delta A}\left[(\epsilon_i-\epsilon_i{}^*)(\boldsymbol{E}_0\cdot\boldsymbol{E}_1^*+\boldsymbol{E}_1\cdot\boldsymbol{E}_0^*)+(\mu_{cp}-\mu_{cp}{}^*)(\boldsymbol{H}_0\cdot\boldsymbol{H}_1{}^*+\boldsymbol{H}_1\cdot\boldsymbol{H}_0{}^*)\right]e^{-2\alpha_0 z}da\,dz}{8\displaystyle\int_z^{z+L}S_0(z)dz}. \qquad (22b)$$

Each of the fields $\boldsymbol{E}_0$, $\boldsymbol{H}_0$, is made up of an infinite set of space harmonics. Because of the attenuation factor, $\exp(-2\alpha_0 z)$, the space harmonic fields are not orthogonal over the interval L so that cross-product terms of the space harmonics will appear in the integrals if $\boldsymbol{E}_0$ and $\boldsymbol{H}_0$ are replaced by $\boldsymbol{E}_{0n}\exp(-j2\pi nz/L)$ and $\boldsymbol{H}_{0n}\exp(-j2\pi nz/L)$, respectively, Therefore, the propagation constant perturbation β_1 will be, in general, a measure of an averaged field in the rod.

If only one space harmonic field has an appreciable amplitude at the rod location, then a cylindrical rod that perturbs primarily the electric field

$$\frac{\chi_e}{1+N_e\chi_e} \gg \frac{\chi_m}{1+N_m\chi_m}$$

may be used. This leads to

$$\beta_1 \cong \omega\delta A \frac{(1 - e^{-2\alpha_0 L})e^{-2\alpha_0 z}}{8\alpha_0 \int_z^{z+L} S_0(z)dz} \frac{\epsilon_0}{2} \cdot \left[\left(\frac{\chi_e}{1 + N_e\chi_e}\right) + \left(\frac{\chi_e}{1 + N_e\chi_e}\right)^*\right] \left| E_{0n} \right|_r^2. \tag{23}$$

It is easily seen that if α_0 approaches zero, (23) approaches (14) (with $\chi_m = 0$). If only a single space harmonic field is assumed to be present everywhere in the structure, then (23) approaches (19a) (with $\chi_m = 0$).

In some periodic circuits, $S_0(z)$ will still vary as $\exp(-2\alpha_0 z)$ so that (23) will simplify to (19a) in these cases. This is true, for example, for a helix inside a glass envelope with the lossy material distributed uniformly around the circumference. It would not be precisely true for a helix supported by lossy rods, but the discrepancy is probably not large. However, for the normal range of traveling wave tube attentuation, $\alpha_0 L$ will be small enough that

$$\frac{1 - e^{-2\alpha_0 L}}{2\alpha_0} \cong L \tag{24}$$

to a good approximation. Then (23) becomes

$$\beta_1 \cong \frac{\omega\delta A}{4} \left\{ \frac{e^{-2\alpha_0 z}}{\frac{1}{L}\int_z^{z+L} S_0(z)dz} \right\} \frac{\epsilon_0}{2} \cdot \left[\left(\frac{\chi_e}{1 + N_e\chi_e}\right) + \left(\frac{\chi_e}{1 + N_e\chi_e}\right)^*\right] \left| E_{0n} \right|_r^2. \tag{25}$$

This relates β_1 to the average power in one period of the structure. For lossy, periodic circuits, the quantity

$$\frac{1}{Le^{-\alpha_0 2}} \int_z^{z+L} S_0(z)dz/Le^{-2\alpha_0 z}$$

is the proper average value of power to insert into the interaction impedance formula, so that

$$Z_n \cong \frac{4\beta_1}{\omega\delta A\beta_n^2\epsilon_0 \left[\left(\frac{\chi_e}{1 + N_e\chi_e}\right) + \left(\frac{\chi_e}{1 + N_e\chi_e}\right)^*\right]}, \tag{26}$$

where Z_n is the interaction impedance of the nth space harmonic, recalling that only the nth space harmonic has an appreciable amplitude at the rod location, and $\beta_n = \beta_0 + 2\pi n/L$. Thus, a cylindrical rod is an adequate perturbation for a lossy glass enclosed helix as well as a lossy rod supported helix if the measurements are made on the helix axis where only the fundamental space harmonic field exists.

In regions where several space harmonics have appreciable amplitudes, a periodic array of beads may be used to determine Z_n. It will probably be necessary to use beads whose geometry is such as to cause an anisotropic perturbation in order to determine the field along a particular direction of interest. One effective arrangement is to use an array of needle shaped beads. For large length-to-diameter ratios, these will cause a perturbation when there is a component of field parallel to the long dimension but relatively little perturbation for components perpendicular to this direction. If the bead length as well as the cross section is small compared to a wavelength, then the field inside each bead is uniform and (22a) becomes

$$\beta_1 \cong \frac{\omega\delta V_b e^{-2\alpha_0 z'} \frac{\epsilon_0}{2}\left[\left(\frac{\chi_e}{1 + N_e\chi_e}\right) + \left(\frac{\chi_e}{1 + N_e\chi_e}\right)^*\right](\boldsymbol{E}_0 \cdot \boldsymbol{E}_0^*)_{z'}}{4\int_z^{z+L} S_0(z)dz}, \tag{27}$$

where z' denotes the position of the bead in the period of the structure under consideration. δV_b is the volume of one bead. $(\boldsymbol{E}_0^* \cdot \boldsymbol{E}_0)_{z'}$ may be written as

$$(\boldsymbol{E}_0 \cdot \boldsymbol{E}_0^*)_{z'} = \sum_n \sum_m \boldsymbol{E}_{0n} \cdot \boldsymbol{E}_{0m}^* e^{-j2\pi(n-m)z'/L} \tag{28}$$

which displays the periodic nature of this term. If β_1 is measured as a function of bead position, z', as the periodic array of beads is moved through one complete period of the structure, then Z_n can be determined. The plot of β_1 vs z' is seen from (27) and (28) to be given by a product of an exponential function $\exp(-2\alpha_0 z')$ and a periodic function $(\boldsymbol{E}_0 \cdot \boldsymbol{E}_0^*)_{z'}$. After extracting the exponential portion, the remaining periodic curve can be Fourier analyzed to determine the amplitudes of the space harmonic fields. From this, of course, the interaction impedance can be calculated.

IV. CONCLUSIONS

General relations for the perturbation of the real and imaginary parts of the propagation constant of lossy, nonreciprocal, periodic waveguides by a perturbing rod placed parallel to the axis have been developed. The rod may be either cylindrical or periodic, and lossless or lossy. Approximate formulas valid when the perturbation is small are readily obtained if the rod cross section is small compared to the wavelength so that the fields may be considered uniform, or nearly so, inside the rod.

The application of the propagation constant perturbation formulas to the measurement of the interaction impedance of propagating structures can be made, and one can use the perturbation of the phase constant by rods to determine the interaction impedance under fairly general conditions. These include lossy circuits where the attenuation constant is in the usual range for traveling wave tube circuits, and nonreciprocal circuits if the magnetic fields in the ferrite material are primarily circularly polarized. In fact, more general field distributions in the ferrite can be tolerated if the rod perturbation is such that the change in field energy in the ferrite is small relative to the total change in field energy stored in the whole structure. Periodic circuits are also included, and the space harmonic interaction impedance can be determined for these by using a periodic rod and Fourier analyzing the resulting curve of the phase constant vs rod position.

The perturbation of the attenuation constant of a waveguide by a lossy rod can also be used to measure the interaction impedance. The requirements in this case are that the structure be fairly low loss and reciprocal, or at least that the rod geometry and placement be such that the perturbation of the fields in the structure's lossy and nonreciprocal regions be small.

Attention has been directed here toward the use of propagation constant perturbation techniques to determine the interaction impedance of microwave tube circuits such as traveling wave tube or extended interaction klystron circuits. A closely related measurement is the exploration of electromagnetic field distributions in propagating circuits. Since with the proper conditions of small perturbation, etc., the change in the propagation constant is directly proportional to the ratio of the square of the fields divided by the power, the rod may be used to determine the field patterns. A dielectric rod, for example, whose geometry is such as to cause an anisotropic perturbation, may be used to obtain the relative magnitude and direction of the electric fields within the structure. This data, together with data taken using a metallic rod which will perturb both the electric and magnetic fields in general, can be used to deduce the magnetic field distribution. Of course, for a periodic circuit, the exploratory rods must also be periodic to take account of the space harmonic fields and a periodic array of properly shaped beads to give an anisotropic perturbation is useful.

And, of course, the perturbation technique is of great utility for investigating material parameters by using a standard structure whose electromagnetic field distribution is known and perturbing it by introducing the sample of material to be measured. The perturbation formulas developed above are readily applied to measurements of this type. In fact, this type of measurement is very useful in determining the rod parameters for rods to be used in the interaction impedance measurements discussed above at frequencies close to the measurement frequency. This permits the determination of the interaction impedance using purely experimental data for the rod's susceptibility, depolarizing factors, and volume.

Taylor-Cauchy Transforms for Analysis of a Class of Nonlinear Systems*

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Summary—**This paper presents a new transform calculus for analyzing a certain class of nonlinear systems. The method, which can be justified rigorously by the partition theory,[1-3] essentially transforms a nonlinear differential equation having certain conditions imposed on its linear, nonlinear, and driving terms into an algebraic equation. The latter is easily solved recursively owing to its symmetry and convolution properties.**

The transform pair is based on a combination of the Cauchy integral theorem and Taylor's series in complex form. To illustrate the method a number of examples are solved and a table of transforms is included.

Because the results of this transform technique are the same as those given by the partition method under certain circumstances, the two are compared. It is then seen that the solution can be obtained uniquely and exactly.

The Taylor-Cauchy transform method can be compared with the Laurent-Cauchy transform method, given in a companion paper,[4] for the solution of linear systems described by differential-difference and sum equations.

I. INTRODUCTION

THIS paper introduces a transform calculus for analyzing a certain class of nonlinear systems both uniquely and exactly. In brief, the method consists of suitably transforming a nonlinear differential equation, which describes a given physical system, into a corresponding algebraic equation of the recurrent-convolution type. The latter equation is always capable of being solved recursively. In some instances, the recursion equation is solvable in closed form. In either case, the result is inverted or found in the table of Taylor-Cauchy transforms to give back the time function representing the response of the nonlinear network or system under analysis. On the one hand, when the solution of the transform equation is given in open form, the time function takes the form of Taylor's series. On the other hand, when the transform equation is solvable in closed form, its singularities can be found[1,5] and, as a consequence, the behavior of the system for large t is easily determined. When, in addition, the singularities turn out to be poles, the solution or response can be given in closed form.

The method of analysis presented here is applicable to a broad class of physical systems. The conditions specifying this class are explicitly stated in terms of the linear and nonlinear terms and of the driving forces[1-3] of an ordinary nonlinear differential equation such as

$$Z(D)\cdot x(t) + \phi(x, \dot{x}, \cdots) = g(t) \tag{1}$$

where $Z(D)$ is a linear differential operator defined as

$$Z(D) = \sum_{n=0}^{N_1} \alpha_n D^n \tag{2}$$

in which the α's are constants required to satisfy the condition that

$$y(t) = 0(e^{\tau_1 t}) \tag{3}$$

such that

$$y(t) = \frac{1}{2\pi j}\int_{Br} \frac{e^{st}}{Z(s)}\,ds \tag{4}$$

and

t is a real time variable,
s is a complex-frequency variable,
τ_1 is a constant specifying the type of $y(t)$,
$y(t)$ is the impulsive response of the linear part of (1),
Br denotes the proper Wagner-Bromwich contour in the s-plane,
$\phi(x, \dot{x}, \cdots)$ is a nonlinear function of the response and its derivatives, as the case may be, and is required to satisfy a modified Lipschitz condition discussed below,
$g(t)$ denotes the forcing function required to satisfy a condition like (3).

II. RESTRICTIONS ON SYSTEM

It was shown by Wolf[1-3] that under certain broad conditions the differential equation (1) represented a physical system so that the solution, $x(t)$, is governed by functions of exponential type. These conditions which

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* Original manuscript received by the IRE, May 25, 1959; revised manuscript received December 11, 1959. This work was done under a research grant from the National Science Foundation.

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hold for the partition method also hold for the Taylor-Cauchy transforms. They are listed below for reference:

1) The linear operator $Z(D)$ has an impulsive response $y(t)$ of exponential type and order one.
2) The forcing function $g(t)$ is a function of exponential type and order one.
3) The nonlinear function $\phi(x, \dot{x}, \cdots)$ is single-valued and continuous and satisfies the following condition:

   Given a pair of positive constants M and a and two continuous functions $u(t)$ and $v(t)$ which are asymptotically like e^{-at}, then ϕ must satisfy the condition that

   $$|\phi[v(t)] - \phi[u(t)]| < Me^{-at}|v(t) - u(t)|$$

   for all $t \geq 0$.

In Wolf,[2] it is shown that the polynomial satisfies restriction 3) under certain conditions. Some transcendents[6] whose inverse functions possess algebraic derivatives can also be made to satisfy restriction 3). In this paper transforms are developed for the case in which ϕ is a polynomial nonlinearity such as

$$\phi(x) = \sum_{n=2}^{N_2} \beta_n x^n. \tag{5}$$

It is noted that any power-function combination of x and its derivatives is also admitted[3] in this method.

Eq. (1) as restricted possesses a unique solution which is an analytic function of t. Polynomials composed of the solution and its derivatives are also analytic functions. Hence, if terms are transposed from the left to the right member of (1), the new right member is an analytic function and may be written as a Taylor series.

In the partition method, from which the Taylor-Cauchy transform method is developed, the nonlinear terms in (1) are transposed. The combination of the forcing function, $g(t)$, and these transposed terms defines the *auxiliary forcing function*, $f(t)$, which is expressed as a Taylor series, the coefficients of which must be solved for. This is accomplished by convolving the series with the impulsive response of the linear terms in the left member to obtain an expression for $x(t)$ in terms of the coefficients of the series. This expression for $x(t)$ is substituted in the defining equation for the auxiliary forcing function to yield the coefficients.

Some or all of the linear terms except the term containing the *highest derivative* may also be transposed and included in the auxiliary forcing function. The auxiliary forcing function thus defined is, of course, a different function from that obtained when only the nonlinear terms are transposed. No matter how terms containing $x(t)$ and its derivatives (except the highest derivative) are transposed from the left to the right member of (1), the unique solution, $x(t)$, is obtained. Taylor-Cauchy transform methods yield the same solution in a more direct manner.

III. Description of the Method

Eq. (1) can be transformed into (6) below by the Taylor-Cauchy transformation, namely,

$$\mathfrak{J}_c[Z(D)\cdot x(t)] + \mathfrak{J}_c[\phi(x, x, \cdots)] = \mathfrak{J}_c[g(t)] \tag{6}$$

where $\mathfrak{J}_c$, the direct transform, is defined by

$$\mathfrak{J}_c[F(\lambda)] = \frac{1}{2\pi j}\int_C \frac{F(\lambda)}{\lambda^{n+1}}\,d\lambda, \qquad n = 0, 1, 2, \cdots \tag{7}$$

in which λ is a complex time variable[5] which replaces the real variable t in this transform method, and $F(\lambda)$ is any of the quantities inside the brackets in which t is replaced by λ and x is replaced by W. Thus

$$\begin{aligned} F_1(\lambda) &= Z(D)\cdot W(\lambda) \\ F_2(\lambda) &= \phi(W, \dot{W}, \cdots) \\ F_3(\lambda) &= G(\lambda) \\ D &= \frac{d}{d\lambda} \\ W &= W(\lambda) \\ \dot{W} &= \frac{dW(\lambda)}{d\lambda}. \end{aligned} \tag{8}$$

C denotes a closed contour in the λ-plane enclosing the singularities of $F(\lambda)$, and n is a discrete variable taking on discrete values $0, 1, 2, \cdots$.

It is noted that (6) is written as the sum of the transforms of the parts of (1), rather than as the transform of the sum of the parts of (1). In addition, the operation $\mathfrak{J}_c$ is commutative with a constant. That is to say,

$$\mathfrak{J}_c[aF(\lambda)] = a\mathfrak{J}_c[F(\lambda)]. \tag{9}$$

The additivity and commutivity properties of $\mathfrak{J}_c$ are often referred to in engineering literature as the linearity property of the transform. These properties follow immediately from the definition of the transform given in (7).

After performing the operations indicated in (6), one obtains a recurrence relation in a new function w_n, where $w_{n,k}$ is the $\mathfrak{J}_c$-transform mate of $W^{(k)}(\lambda)$, in which n is the discrete variable in the real positive n-half-line corresponding to the complex variable λ in the λ-plane, and k is the order of the system under analysis. This new equation is solved for w_n and by means of the inverse transform, $\mathfrak{J}_c^{-1}$, the response function, $W^{(k)}(\lambda)$, is recovered. This is the kth derivative of the desired solution. The inverse transform is given by

$$\mathfrak{J}_c^{-1}[w_n] = \sum_{n=0}^{\infty} w_n\lambda^n = W^{(k)}(\lambda). \tag{10}$$

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[6] A. A. Wolf, "Analysis of Transcendental Nonlinear Systems," presented at the Summer General Meeting of AIEE, Buffalo, N. Y., paper 58-995; June 25, 1958.

Formally, then, applying (7) to (1) and noting (8) and (9), one sees that (6) becomes

$$\frac{1}{2\pi j}\int_C \frac{F_1(\lambda)}{\lambda^{n+1}}\,d\lambda + \frac{1}{2\pi j}\int_C \frac{F_2(\lambda)}{\lambda^{n+1}}\,d\lambda = \frac{1}{2\pi j}\int_C \frac{F_3(\lambda)}{\lambda^{n+1}}\,d\lambda \tag{11}$$

whereupon utilizing (2) and (5) leads to

$$\frac{1}{2\pi j}\int_C \frac{F_1(\lambda)}{\lambda^{n+1}}\,d\lambda = \frac{1}{2\pi j}\int_C \sum_{k=0}^{N_1} \alpha_k W^{(k)}(\lambda)\,\frac{d\lambda}{\lambda^{n+1}} \tag{12}$$

$$\frac{1}{2\pi j}\int_C \frac{F_2(\lambda)}{\lambda^{n+1}}\,d\lambda = \frac{1}{2\pi j}\int_C \sum_{k=2}^{N_2} \beta_k W^{k}(\lambda)\,\frac{d\lambda}{\lambda^{n+1}} \tag{13}$$

and

$$\frac{1}{2\pi j}\int_C \frac{F_3(\lambda)}{\lambda^{n+1}}\,d\lambda = \frac{1}{2\pi j}\int_C \frac{g(\lambda)}{\lambda^{n+1}}\,d\lambda. \tag{14}$$

IV. The Taylor-Cauchy Transform: Its Properties and Derivation

The Taylor-Cauchy transform is defined by the following pair of equations:

$$W^{(k)}(\lambda) = \sum_{n=0}^{\infty} w_{n,k}\lambda^n \tag{15}$$

and

$$w_{n,k} = \frac{1}{2\pi j}\int_C \frac{W^{(k)}(\lambda)}{\lambda^{n+1}}\,d\lambda \tag{16}$$

where

k denotes the order of the system, *i.e.*, the order of the highest linear derivative in the differential equation describing the system;

n is a running discrete positive index taking values 0, 1, 2, · · · ;

$W^{(k)}(\lambda)$ denotes the kth derivative of a time function; and

$w_{n,k}$ denotes the transform of $W^{(k)}(\lambda)$.

This transfomation pair will now be established. In another paper[1] it is shown that in order to develop recursion formulas which will uniquely solve (1), among other things,[7] it is sufficient to partition at the highest-order linear derivative. Following this idea and noting, moreover, the analytic existence of (1), we are entitled to write (15).[8] It should be noted that if any other derivative were selected, one could not ensure obtaining a recurrence relation which would be solvable. Furthermore, if the partition is made at any other derivative, it is easy to show examples of nonlinear differential equations that yield nonconvergent or false results. This difficulty does not arise in linear systems; hence, one can assume a power series solution for such systems.

Eq. (15) is an infinite series uniformly convergent in some circle. Generally, since $W(\lambda)$ is an entire function of exponential type, the circle is the entire λ-plane. This usually occurs in the physical nondissipationless networks. As a consequence we require

$$w_{n,k} = 0 \quad \text{when} \quad n < 0 \text{ and for all } k. \tag{17}$$

Multiplying both members of (15) by λ^{-m-1} gives

$$\lambda^{-m-1}W^{(k)}(\lambda) = \lambda^{-m-1}\sum_{n=0}^{\infty} w_{n,k}\lambda^n \tag{18}$$

where $m>0$ and is an integer. Since n is only a running index of the sum, (18) may be written

$$\lambda^{-m-1}W^{(k)}(\lambda) = \sum_{n=0}^{\infty} w_{n,k}\lambda^{n-m-1}. \tag{19}$$

Let us select a suitable circular-closed contour C in the λ-plane with its center at the origin, the radius of which is such that all the poles of $\lambda^{-m-1}W^{(k)}(\lambda)$ are enclosed. With this contour C we integrate (19):

$$\frac{1}{2\pi j}\int_C \frac{W^{(k)}(\lambda)}{\lambda^{m+1}}\,d\lambda = \frac{1}{2\pi j}\int_C \sum_{n=0}^{\infty} w_{n,k}\lambda^{n-m-1}d\lambda. \tag{20}$$

Since (15) is uniformly convergent, the order of summation and integration may be interchanged. This gives

$$\frac{1}{2\pi j}\int_C \frac{W^{(k)}(\lambda)}{\lambda^{m+1}}\,d\lambda = \sum_{n=0}^{\infty} w_{n,k}\,\frac{1}{2\pi j}\int_C \lambda^{n-m-1}d\lambda. \tag{21}$$

Now consider the integral in the right-hand member of (21). From Cauchy's integral theorem this integral is unity when $n=m$, and zero otherwise. Consequently, the integral is formally recognized as a Kronecker delta function, *i.e.*,

$$\frac{1}{2\pi j}\int_C \lambda^{n-m-1}d\lambda = \delta_{n-m} \tag{22}$$

where

$$\delta_{n-m} = \begin{cases} 1, & n = m \\ 0, & n \neq m \end{cases}. \tag{23}$$

Substituting (22) in (21) yields

$$\frac{1}{2\pi j}\int_C \frac{W^{(k)}(\lambda)}{\lambda^{m+1}}\,d\lambda = \sum_{n=0}^{\infty} w_{n,k}\delta_{n-m} \tag{24}$$

from which (16) immediately follows. Therefore (15) and (16) define a transformation pair. Using this pair, one can develop a table of transforms.

It was pointed out earlier that W replaces x and λ replaces t. Since t is a real variable, x is a function of a real variable. Because of the analytic properties of x we can extend this function by the principle of analytic continuation, thereby giving rise to a function of a complex variable $W(\lambda)$. Ku and Wolf[5] show how one can utilize information obtained in the complex λ-plane to determine the degree of stability of a system along the real half-line t.

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[7] See Section II.

[8] The right member of (15) is uniformly convergent in some circle in the λ-plane, the center of which is at the origin.

V. OPERATIONAL PROPERTIES

We note that the Taylor-Cauchy transforms satisfy the following operational properties:

$$\mathfrak{J}_c\{\mathfrak{J}_c^{-1}[1]\} = \mathfrak{J}_c^{-1}\{\mathfrak{J}_c[1]\} \tag{25}$$

$$\mathfrak{J}_c[F(\lambda)] \neq F(\lambda)\cdot\mathfrak{J}_c[1] \tag{26}$$

$$\mathfrak{J}_c[0] = 0\cdot\mathfrak{J}_c[1] = 0 \tag{27}$$

$$\mathfrak{J}_c(1) = \delta_n \text{ (Kronecker's delta function)} \tag{28}$$

$$\mathfrak{J}_c^{-1}[1] = \frac{1}{1-\lambda} \quad \text{in } |\lambda| < 1 \tag{29}$$

$$D\cdot\mathfrak{J}_c^{-1}[1] \neq \mathfrak{J}_c^{-1}[D\cdot 1]. \tag{30}$$

We note in (30) particularly that

$$D\cdot\mathfrak{J}_c^{-1}[1] = \frac{d}{d\lambda}\left(\frac{1}{1-\lambda}\right) \quad \text{(from 29)}$$

so that

$$D\cdot\mathfrak{J}_c^{-1}[1] = \frac{-1}{(1-\lambda)^2} \tag{31}$$

and

$$D^n\cdot\mathfrak{J}_c^{-1}[1] = \frac{(-1)^n}{(1-\lambda)^{n+1}}\cdot \tag{32}$$

We also note that

$$D^{-1}\cdot\mathfrak{J}_c^{-1}[1] = -\log\left(\frac{1}{1-\lambda}\right) = \log(1-\lambda). \tag{33}$$

VI. EXAMPLES OF TAYLOR-CAUCHY TRANSFORM PAIRS

A. *Operational Pairs: The Mates* $F(\lambda)\Leftrightarrow f_n$

1) Additivity:[9]

$$\mathfrak{J}_c[F_1(\lambda)+F_2(\lambda)] = \mathfrak{J}_c[F_1(\lambda)] + \mathfrak{J}_c[F_2(\lambda)]$$

Proof:

$$\mathfrak{J}_c[F_1(\lambda)+F_2(\lambda)] = \frac{1}{2\pi j}\int_C \frac{F_1(\lambda)+F_2(\lambda)}{\lambda^{n+1}}\,d\lambda. \tag{34}$$

Since the integral of a sum is equal to the sum of its integrals,

$$\mathfrak{J}_c[F_1(\lambda)+F_2(\lambda)] = \mathfrak{J}_c[F_1(\lambda)] + \mathfrak{J}_c[F_2(\lambda)]. \tag{35}$$

2) Commutivity:[10]

$$\mathfrak{J}_c[aF(\lambda)] = a\mathfrak{J}_c[F(\lambda)]$$

Proof:

$$\mathfrak{J}_c[aF(\lambda)] = \frac{1}{2\pi j}\int_C \frac{aF(\lambda)}{\lambda^{n+1}}\,d\lambda = a\mathfrak{J}_c[F(\lambda)]. \tag{36}$$

3) Change of Scale:

$$\mathfrak{J}_c\left[F\left(\frac{\lambda}{a}\right)\right] = \frac{\mathfrak{J}_c[F(\lambda)]}{a^n}$$

Proof:

$$\mathfrak{J}_c\left[F\left(\frac{\lambda}{a}\right)\right] = \frac{1}{2\pi j}\int_C F\left(\frac{\lambda}{a}\right)\lambda^{-n-1}d\lambda. \tag{37}$$

Let $\zeta=\lambda/a$. Hence, $d\zeta=d\lambda/a$ and the right member of (37) becomes

$$\frac{1}{2\pi j}\int_C F(\zeta)(\zeta a)^{-n-1}a\,d\zeta = \frac{1}{2\pi j}\int_C \frac{F(\zeta)}{a^n\zeta^{n+1}}\,d\zeta \tag{38}$$

so that

$$\mathfrak{J}_c\left[F\left(\frac{\lambda}{a}\right)\right] = a^{-n}\mathfrak{J}_c[F(\lambda)]. \tag{39}$$

4) Initial Value:

$$\lim_{\lambda\to 0} F(\lambda) = \lim_{n\to 0} f_n.$$

This follows immediately from the definition of the direct transform.

B. *Terms Involving* λ^m

1) $\mathfrak{J}_c[\lambda^m] = \delta_{n-m}$, where $n, m = 0, 1, 2, \cdots$.

Thus

$$\mathfrak{J}_c[\lambda^m] = \frac{1}{2\pi j}\int_C \lambda^{m-n-1}d\lambda = \delta_{n-m}. \tag{40}$$

2) $\mathfrak{J}_c[\lambda^m]=0$ when m is nonintegral.

This result follows from (40), noting that n is always integral-valued.

C. *Terms in* $W^{(k-m)}(\lambda)$

1)
$$\mathfrak{J}_c[W^{(k-1)}(\lambda)] = \frac{w_{n-1,k}}{n} + A_{k-1}\delta_n. \tag{41}$$

If $W^{(k)}(\zeta)$ is the kth derivative of W with respect to ζ and is analytic in a region of the ζ-plane, and if 0 and λ are the terminal points of any path lying within this analytic region,

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[9] This signifies that the operator is distributive with respect to addition and assumes that both terms in the right-hand member exist.

[10] This signifies that the operator is commutative with respect to multiplication by a constant.

$$\int_0^\lambda W^{(k)}(\zeta)d\zeta = W^{(k-1)}(\lambda) - W^{(k-1)}(0) \tag{42}$$

or

$$W^{(k-1)}(\lambda) = \int_0^\lambda W^{(k)}(\zeta)d\zeta + A_{k-1} \tag{43}$$

where

$$A_{k-1} = W^{(k-1)}(0). \tag{44}$$

Substituting (15) into (43) gives, on interchanging the order of summation and integration,

$$W^{(k-1)}(\lambda) = \sum_{n=0}^{\infty} \frac{w_{n,k}}{n+1} \lambda^{n+1} + A_{k-1}. \tag{45}$$

Transforming (45) according to (16) yields

$$\begin{aligned} \mathfrak{Z}_c[W^{(k-1)}(\lambda)] &= \frac{1}{2\pi j}\int_C \sum_{m=0}^{\infty} \frac{w_{m,k}}{m+1} \lambda^{m+1}\lambda^{-n-1}d\lambda \\ &\quad + \frac{1}{2\pi j}\int_C A_{k-1}\lambda^{-n-1}d\lambda \\ &= \frac{w_{n-1}}{n} + A_{k-1}\delta_n. \end{aligned} \tag{46}$$

2) $\mathfrak{Z}_c[W^{(k-2)}(\lambda)] = \frac{w_{n-2,k}}{n(n-1)} + A_{k-1}\delta_{n-1} + A_{k-2}\delta_n.$

If $W^{(k)}(\zeta)$ is analytic in a region of the ζ-plane, then all its derivatives exist and are analytic therein. Consequently,

$$W^{(k-2)}(\lambda) = \int_0^\lambda W^{(k-1)}(\zeta)d\zeta + A_{k-2} \tag{47}$$

where

$$A_{k-2} = W^{(k-2)}(0). \tag{48}$$

Substituting (45) into (47) and performing the indicated integration gives

$$W^{(k-2)}(\lambda) = \sum_{n=0}^{\infty} \frac{w_{n,k}}{(n+1)(n+2)} \lambda^{n+2} + A_{k-1}\lambda + A_{k-2}. \tag{49}$$

Transforming (49) according to (16) yields

$$\begin{aligned} &\mathfrak{Z}_c[W^{(k-2)}(\lambda)] \\ &= \frac{1}{2\pi j}\int_C \sum_{m=0}^{\infty} \frac{w_{m,k}}{(m+1)(m+2)} \lambda^{m+2}\lambda^{-n-1}d\lambda \\ &\quad + \frac{1}{2\pi j}\int_C A_{k-1}\lambda\lambda^{-n-1}d\lambda + \frac{1}{2\pi j}\int_C A_{k-2}\lambda^{-n-1}d\lambda \\ &= \frac{w_{n-2,k}}{n(n-1)} + A_{k-1}\delta_{n-1} + A_{k-2}\delta_n. \end{aligned} \tag{50}$$

3) $\mathfrak{Z}_c[W^{(k-r)}(\lambda)]$

$$= \frac{w_{n-r,k}}{n(n-1)\cdots(n-r+1)} + \sum_{q=1}^{r} \frac{A_{k-q}}{(r-q)!}\delta_{n-r+q}.$$

Proceeding as in the previous cases, we integrate $W^{(k)}(\lambda)$ r times. This gives

$$\begin{aligned} W^{(k-r)}(\lambda) &= \sum_{n=0}^{\infty} \frac{w_{n,k}}{(n+1)(n+2)\cdots(n+r)} \lambda^{n+r} \\ &\quad + \sum_{q=1}^{r} \frac{A_{k-q}}{(r-q)!}\lambda^{r-q} \end{aligned} \tag{51}$$

in which

$$A_{k-q} = W^{(k-q)}(0). \tag{52}$$

Now (51) is transformed according to (16) giving

$$\begin{aligned} &\mathfrak{Z}_c[W^{(k-r)}(\lambda)] \\ &= \frac{1}{2\pi j}\int_C \sum_{m=0}^{\infty} \frac{w_{m,k}}{(m+1)(m+2)\cdots(m+r)} \lambda^{m+r-n-1} d\lambda \\ &\quad + \frac{1}{2\pi j}\int_C \sum_{q=1}^{r} \frac{A_{k-q}}{(r-q)!}\lambda^{r-q-n-1}d\lambda \\ &= \frac{w_{n-r,k}}{n(n-1)(n-2)\cdots(n-r+1)} \\ &\quad + \sum_{q=1}^{r} \frac{A_{k-q}}{(r-q)!}\delta_{n-r+q}. \end{aligned} \tag{53}$$

4) $\mathfrak{Z}_c[W(\lambda)] = \frac{w_{n-k,k}}{n(n-1)\cdots(n-k+1)}$

$$+ \sum_{q=1}^{k} \frac{A_{k-q}}{(k-q)!}\delta_{n-k-q}.$$

This is a special case of (53) in which $r=k$.

D. Terms in $\lambda^\rho W^{(k-r)}(\lambda)$

1) $\mathfrak{Z}_c[\lambda^\rho W^{(k)}(\lambda)] = w_{n-\rho,k}.$

To obtain this transform, first multiply (15) by λ^ρ. Then applying the $\mathfrak{Z}_c$-transform gives

$$\mathfrak{Z}_c[\lambda^\rho W^{(k)}(\lambda)] = \frac{1}{2\pi j}\int_C \sum_{m=0}^{\infty} w_{m,k}\lambda^{m+\rho-n-1}d\lambda = w_{n-\rho,k}. \tag{54}$$

The latter result is obtained on interchanging the order of summation and integration, which is justified because of the uniformity of convergence of the sum.

2) $\mathfrak{Z}_c[\lambda^\rho W^{(k-r)}(\lambda)]$

$$= \frac{w_{n-r-\rho,k}}{(n-\rho)(n-\rho-1)\cdots(n-\rho-r+1)}$$

$$+ \sum_{q=1}^{r} \frac{A_{k-q}}{(r-q)!}\delta_{n-\rho-r+q}.$$

To obtain this result proceed as before by first multiplying $W^{(k-r)}(\lambda)$ by λ^p and then transforming, so that

$$\mathfrak{T}_c[\lambda^p W^{(k-r)}(\lambda)] = \frac{1}{2\pi j}\int_C \sum_{m=0}^{\infty} \frac{w_{m,k}}{(m+1)\cdots(m+r)}\,d\lambda + \frac{1}{2\pi j}\int_C \sum_{q=1}^{r} \frac{A_{k-q}}{(r-q)!}\lambda^{r-q+p-n-1}d\lambda \tag{55}$$

which yields the above result on integration.

E. Transforms of Nonlinear Terms

In the previous paragraphs we have illustrated the use of the Taylor-Cauchy transform to obtain transform mates of linear terms. Now we show how to obtain corresponding mates of nonlinear terms.

1) The Convolution Sums: The higher convolution sums were developed by Wolf in other papers.[1–3] Here we shall collect for reference some of these sums.

Let $C_{n,k,0}^{(\nu)}$ symbolize a transform of the zeroth derivative of a function raised to the νth power. The superscript ν in this case does not represent a derivative as it would in the time function. The subscript 0 refers to the zeroth derivative, and the n and k are defined as previously.

In general let $C_{n,k,0,1,2,\cdots m}^{(\mu)}$ symbolize the transform of the product of the zeroth, first, $\cdots$, and μth derivatives of a given time function. For our purposes let us define

$$C_{n,k,k-r} = \frac{w_{n,k}}{(n+1)(n+2)\cdots(n+r)}. \tag{56}$$

Eq. (56) is a relation between the linear term $w_{n,k}$ and the linear term $C_{n,k,k-r}$. The superscript $\nu=1$ is omitted. When $\nu=0$ the corresponding C is a Kronecker delta function, and the symbol for the latter will always be used instead. Thus

$$C_{n,k}^{(0)} = \delta_n \tag{57}$$

or

$$C_{n-m,k}^{(0)} = \delta_{n-m}. \tag{58}$$

We now develop the higher-order functions of C in terms of its linear function (56):

$$C_{n,k,k-r}^{(2)} = \sum_{q_1=0}^{n} C_{q_1,k,k-r}\, C_{n-q_1,k,k-r}. \tag{59}$$

To display the convolution property sharply, let $k=r$ and drop the second subscript, k. Then (59) becomes

$$C_n^{(2)} = \sum_{q_1=0}^{n} C_{q_1}C_{n-q_1}. \tag{60}$$

$C_n^{(3)}$ and $C_n^{(4)}$ may be written as

$$C_n^{(3)} = \sum_{q_2=0}^{n}\sum_{q_1=0}^{q_2} C_{q_1}C_{q_2-q_1}C_{n-q_2} \tag{61}$$

$$C_n^{(4)} = \sum_{q_3=0}^{n}\sum_{q_2=0}^{q_3}\sum_{q_1=0}^{q_2} C_{q_1}C_{q_2-q_1}C_{q_3-q_2}C_{n-q_3}. \tag{62}$$

In general

$$C_n^{(\nu)} = \sum_{q_{\nu-1}=0}^{n} \cdots \sum_{q_2=0}^{q_3}\sum_{q_1=0}^{q_2} C_{q_1}C_{q_2-q_1}\cdots C_{n-q_{\nu-1}}. \tag{63}$$

Eqs. (60)–(63) display the general procedure for writing convolution sums. We note that the C's which go inside the summations depend on the nature of the problem. Thus (59) shows a case where the C's are obtained from the nonlinearity of degree two in the $(k-r)$th derivative of a function.

In writing the above equations q denotes a running index with the subscript of q denoting a particular running index. The latter subscript is always one less than the order of the C in the left member, and the number of sums is also one less than the order of the C in the left member. We note also that the C's inside the summation sign have subscripts beginning with q_1. The next subscript is found by subtracting the running index of the inside summation from its upper bound, namely, q_2-q_1. The process is continued until all the necessary sums are written.

2) Certain Simplifying Procedures in Subscripts and Equations: If k is taken to be the order of the highest derivative of the nonlinear differential equation under analysis, then it turns out that the w's become independent of the second subscript, k, if all the terms are referred to the second subscript. To illustrate this, assume $k=2$. Then the following pairs result for the second and first derivatives in the absence of initial conditions:

$$W^{(2)}(\lambda) \Leftrightarrow w_{n,2} \tag{64}$$

and

$$W^{(1)}(\lambda) \Leftrightarrow w_{n,1}. \tag{65}$$

If (65) is developed in terms of the highest-order derivative, *i.e.*, $k=2$, it becomes

$$W^{(1)}(\lambda) \Leftrightarrow \frac{w_{n,2}}{n} = w_{n,1}. \tag{66}$$

It is evident that if (64) and (66) are used, the symbol $w_{n,2}$ is now independent of $k(=2)$. To show this further consider the following example of a third-order system:

$$\dddot{x} + \ddot{x} + x\ddot{x} = b \tag{67}$$

subject to the conditions at $t=0$

$$x(0) = a \tag{67a}$$

$$\dot{x}(0) = b \tag{67b}$$

$$\ddot{x}(0) = 0. \tag{67c}$$

Replacing x by W and t by λ as described above and applying the Taylor-Cauchy transform, one obtains the following recursion formula:

$$w_{n,3} = -C^{(2)}_{n-4,3,0,2} - b\frac{w_{n-2,3}}{n-1} - a\frac{w_{n-1,3}}{n} - \frac{w_{n-2,3}}{n(n-1)} - \frac{w_{n-1,3}}{n} \tag{68}$$

where

$$C^{(2)}_{n-4,3,0,2} = \sum_{q_1=0}^{n-4} \frac{w_{q_1,3}w_{n-q_1-4,3}}{(q_1+1)(q_1+2)(q_1+3)(q_1-n-3)}. \tag{69}$$

We note that on referring everything to the third derivative the subscript $k(=3)$ is superfluous since w is independent of k under these conditions. *Therefore, whenever the terms in the transform are all referred to the highest order derivative we shall drop the second subscript, k, so that $w_{n,3}$ becomes simply w_n in this example.*

3) *Certain Nonlinear Transform Pairs Containing Terms in* $[W^{(k-r)}(\lambda)]^\nu$:

a) *Zero initial conditions:* Given $A_{k-1}=A_{k-2}=\cdots=A_{k-r}=0$, then

$$[W^{(k-r)}(\lambda)]^\nu = \left[\sum_{n=0}^{\infty} C_{n,k,k-r}\lambda^{n+r}\right]^\nu \tag{70}$$

where $C_{n,k,k-r}$ is defined by (56). First factor out λ^r, to give

$$[W^{(k-r)}(\lambda)]^\nu = \lambda^{\nu r}\left[\sum_{n=0}^{\infty} C_{n,k,k-r}\lambda^{n}\right]^\nu. \tag{71}$$

Utilizing the results of Section VI-E, 1) on convolution sums, we may write (71) as[11]

$$[W^{(k-r)}(\lambda)]^\nu = \lambda^{\nu r}\sum_{n=0}^{\infty} C^{(\nu)}_{n,k,k-r}\lambda^{n}. \tag{72}$$

Transforming (72) yields

$$\mathfrak{J}_c[\{W^{(k-r)}(\lambda)\}^\nu] = \frac{1}{2\pi j}\int_C \sum_{m=0}^{\infty} C^{(\nu)}_{m,k,k-r}\lambda^{m+\nu r-n-1}\,d\lambda$$
$$= C^{(\nu)}_{n-\nu r,k,k-r}. \tag{73}$$

b) Nonzero Initial Conditions. Given $A_{k-1}\neq A_{k-2}\neq\cdots\neq A_{k-r}\neq 0$,

$$[W^{(k-r)}(\lambda)]^\nu = \left[\sum_{n=0}^{\infty}\frac{w_{n,k}}{(n+1)(n+2)\cdots(n+r)}\lambda^{n+r} + \sum_{q=1}^{r}\frac{A_{k-q}}{(r-q)!}\right]^\nu. \tag{74}$$

Utilizing the binomial theorem, we may write (74) as

$$[W^{(k-r)}(\lambda)]^\nu = \sum_{i=0}^{\nu}\binom{\nu}{i}\left[\sum_{n=0}^{\infty}\frac{w_{n,k}}{(n+1)(n+2)\cdots(n+r)}\lambda^{n+r}\right]^{\nu-i}\cdot\left[\sum_{q=1}^{r}\frac{A_{k-q}}{(r-q)!}\lambda^{r-q}\right]^i$$
$$= \sum_{n=0}^{\infty} C^{(\nu)}_{n-\nu r,k,k-r}\lambda^n + \sum_{n=0}^{\infty}\sum_{i=1}^{\nu-1}\binom{\nu}{i}\sum_{q=1}^{r} C^{(\nu-i)}_{n-(\nu-i+1)r-q,k,k-r}A^{(i)}_{r-q}\lambda^n + \sum_{q=1}^{r} A^{(\nu)}_{r-q}\lambda^{r-q} \tag{75}$$

in which $A^{(i)}_{r-q}$ and $A^{(\nu)}_{r-q}$ are defined generally by

$$A^{(j)}_{r-q} = \sum_{\beta_{j-1}=0}^{r-q}\cdots\sum_{\beta_2=0}^{\beta_3}\sum_{\beta_1=0}^{\beta_2}\frac{A_{k+\beta_1-r}}{\beta_1!}\,\frac{A_{k+\beta_2-\beta_1-r}}{(\beta_2-\beta_1)!}\cdots\frac{A_{k-\beta_{j-1}-q}}{(r-q-\beta_{j-1})!}. \tag{76}$$

Transforming (75) yields the following result:

$$\mathfrak{J}_c[\{W^{(k-r)}(\lambda)\}^\nu] = C^{(\nu)}_{n-\nu r,k,k-r} + \sum_{i=1}^{\nu-1}\sum_{q=1}^{r}\binom{\nu}{i}C^{(\nu-i)}_{n-(\nu-i+1)r-q,k,k-r}A^{(i)}_{r-q} + \sum_{q=1}^{r} A^{(\nu)}_{r-q}\delta_{n-r+q}. \tag{77}$$

In (77) the first term in the right-hand member is the transform of the function for zero initial conditions, the double sum is the transform of the cross products, and the third sum is the transform of the initial conditions raised to the νth power.

4) *Transform of Nonlinear Terms in* $[W^{(k-r_1)}(\lambda)][W^{(k-r_2)}(\lambda)]$:

a) *Zero initial conditions:* Given $A_{k-1}=A_{k-2}=\cdots=A_{k-r_1}=A_{k-r_2}=0$, the product becomes

$$[W^{(k-r_1)}(\lambda)][W^{(k-r_2)}(\lambda)] = \left[\sum_{n=0}^{\infty}\frac{w_{n,k}}{(n+1)(n+2)\cdots(n+r_1)}\lambda^{n+r_1}\right]\cdot\left[\sum_{n=0}^{\infty}\frac{w_{n,k}}{(n+1)(n+2)\cdots(n+r_2)}\lambda^{n+r_2}\right]$$
$$= \sum_{n=0}^{\infty} C^{(2)}_{n,k,k-r_1,k-r_2}\lambda^{n+r_1+r_2} \tag{78}$$

in which the coefficient of λ in (78) is defined as above and is recorded in the Appendix. On transforming (78), we obtain

$$\mathfrak{J}_c[\{W^{(k-r_1)}(\lambda)\}\{W^{(k-r_2)}(\lambda)\}] = C^{(2)}_{n-r_1-r_2,k,k-r_1,k-r_2}. \tag{79}$$

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[11] For convenience $C^{(\nu)}_{n,k,k-r}$ is defined in Table I, page 921. The second subscript, k, is dropped there in accordance with Section VI-E, 2).

b) *Nonzero initial conditions:* Given $A_{k-1} \neq A_{k-2} \neq \cdots \neq A_{k-r_1} \neq \cdots \neq A_{k-r_2} \neq 0$ and $r_2 > r_1$, the product becomes

$$[W^{(k-r_1)}(\lambda)][W^{(k-r_2)}(\lambda)]$$

$$= \left[\sum_{n=0}^{\infty} \frac{w_{n,k}}{(n+1)(n+2)\cdots(n+r_1)} \lambda^{n+r_1} + \sum_{q=1}^{r_1} \frac{A_{k-q}}{(r_1-q)!} \lambda^{r_1-q} \right]$$

$$\cdot \left[\sum_{n=0}^{\infty} \frac{w_{n,k}}{(n+1)(n+2)\cdots(n+r_2)} \lambda^{n+r_2} + \sum_{q=1}^{r_2} \frac{A_{k-q}}{(r_2-q)!} \lambda^{r_2-q} \right]. \tag{80}$$

After multiplying the above sums, applying the technique used previously, and denoting by $A^{(2)}_{n,k,r_1,r_2}$ the sum

$$A^{(2)}_{n,k,r_1,r_2} = \sum_{\beta=0}^{r_1-1} \frac{A_{k+\beta-r_1}}{\beta!} \frac{A_{k+n-\beta-r_2}}{(n-\beta)!} \tag{81}$$

transforming the result yields

$$\mathfrak{J}_c[\{W^{(k-r_1)}(\lambda)\}\{W^{(k-r_2)}(\lambda)\}] = C^{(2)}_{n-r_1-r_2,k,k-r_1,k-r_2}$$

$$+ \sum_{q=1}^{r_2} \frac{A_{k-q}}{(r_2-q)!} \frac{w_{n-r_1-r_2+q,k}}{(n-r_1-r_2+q+1)(n-r_1-r_2+q+2)\cdots(n-r_2+q)}$$

$$+ \sum_{q=1}^{r_1} \frac{A_{k-q}}{(r_1-q)!} \frac{w_{n-r_1-r_2+q,k}}{(n-r_1-r_2+q+1)(n-r_1-r_2+q+2)\cdots(n-r_1+q)}$$

$$+ \sum_{m=0}^{r_1+r_2-2} A^{(2)}_{m,k,r_1,r_2} \delta_{n-m}. \tag{82}$$

In a similar manner transforms for higher-order products of nonlinear and linear terms may be obtained. Taylor-Cauchy transform pairs are given in Tables II–IV on pages 921–922.

VII. Application of Taylor-Cauchy Transform to Solution of Nonlinear Differential Equations Arising from Circuits

Example 1: Consider a series *RL* circuit shown in Fig. 1. The inductor, *L*, is linear; while the resistor, *R*, is nonlinear, varying in direct proportion to the instantaneous current flowing through it. If the circuit is initially quiescent and a unit voltage step is applied at $t=0$, the resulting nonlinear differential equation is

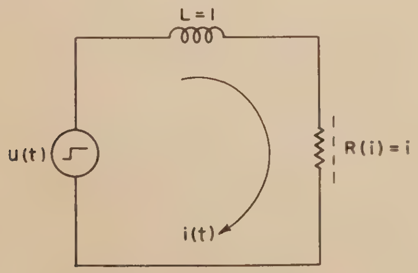

Fig. 1—First-order nonlinear circuit.

$$\frac{di}{dt} + i^2 = u(t) \tag{83}$$

for $L=1$ and $R=i$, where $u(t)$ is the unit step defined in the conventional manner. Also,

$$i(0) = 0. \tag{84}$$

Since (83) is a first-order equation, $k=1$.

Writing $W^{(1)}(\lambda)$ for di/dt and $[W(\lambda)]^2$ for i^2 gives

$$W^{(1)}(\lambda) + [W(\lambda)]^2 = 1 \tag{85}$$

and

$$A_0 = 0. \tag{86}$$

Transforming (85) with the aid of Table III appearing at the end of the paper leads to

$$w_n + C^{(2)}_{n-2,0} = \delta_n \tag{87}$$

in which

$$C^{(2)}_{n-2,0} = \sum_{\beta=0}^{n-2} \frac{w_\beta}{\beta+1} \frac{w_{n-\beta-2}}{n-\beta-1}. \tag{88}$$

We note that the subscript $k(=1)$ is dropped in accordance with the remarks in Section VI-E, 2). Thus

$$w_{n,1} = w_n. \tag{89}$$

Solving (87) and (88) for w_n gives, recursively,

$$w_0 = 1$$

$$w_1 = 0$$

$$w_2 = -1$$

$$w_3 = 0$$

$$w_4 = \frac{2}{3}$$

$$w_5 = 0$$

$$w_6 = -\frac{17}{45}. \qquad (90)$$

$$\cdots$$

Since

$$W(\lambda) = \sum_{n=1}^{\infty} \frac{w_{n-1}}{n} \lambda^n + A_0 \qquad (91)$$

for this case, the solution is obtained on substituting (86) and (90) into (91):

$$W(\lambda) = \lambda - \frac{\lambda^3}{3} + \frac{2}{15}\lambda^5 - \frac{17}{315}\lambda^7 + \cdots. \qquad (92)$$

But (92) is recognized as the series expansion of the hyperbolic tangent. Hence

$$W(\lambda) = \tanh \lambda \qquad (93)$$

and

$$i(t) = \tanh t \qquad (94)$$

Example 2: Consider the nonlinear circuit shown in Fig. 2 having the initial conditions

$$i(0) = -1 \qquad (95)$$

$$v_c(0) = 1 \qquad (96)$$

with parameters as shown and a forcing function $V = \frac{1}{2}e^{-2t}$. The nonlinear integro-differential equation of this circuit is, on applying the initial conditions,

$$\frac{di}{dt} + \left(2 + \frac{i}{2}\right) i + \int_0^t i \, d\tau + 1 = \frac{1}{2} e^{-2t}. \qquad (97)$$

We note that using (95) together with (97) gives

$$\frac{di(0)}{dt} = 1. \qquad (98)$$

Clearing (97) of integrals by differentiating yields

$$\frac{d^2 i}{dt^2} + (2 + i)\frac{di}{dt} + i = -e^{-2t}. \qquad (99)$$

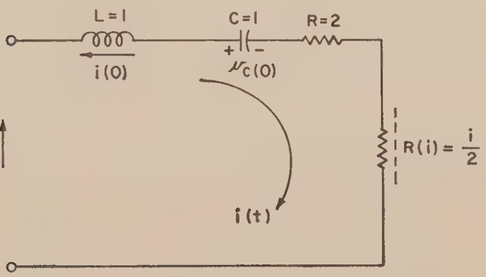

Fig. 2—Second-order nonlinear circuit.

Now we see that $k = 2$. Thus writing $W^{(2)}(\lambda)$ for $d^2 i/dt^2$, $W^{(1)}(\lambda)$ for di/dt, and $W(\lambda)$ for i leads to the equation

$$W^{(2)}(\lambda) + 2W^{(1)}(\lambda) + [W^{(1)}(\lambda)][W(\lambda)] + W(\lambda) = -e^{-2\lambda} \qquad (100)$$

with

$$A_0 = -1 \qquad (101)$$

$$A_1 = 1. \qquad (102)$$

Applying the Taylor-Cauchy transform with the aid of Table III gives

$$w_n = -\frac{(-2)^n}{n!} - 2\delta_{n-1} - \frac{w_{n-1}}{n} - 2\frac{w_{n-2}}{n(n-1)} - \frac{w_{n-2}}{n-1} - C^{(2)}_{n-3,1,0} \qquad (103)$$

where

$$C^{(2)}_{n-3,1,0} = \sum_{\beta=0}^{n-3} \frac{w_\beta}{\beta+1} \frac{w_{n-\beta-3}}{(n-\beta-2)(n-\beta-1)}. \qquad (104)$$

Solving (103) and (104) recursively for w_n gives

$$w_0 = -1$$

$$w_1 = 1$$

$$w_2 = -\frac{1}{2}$$

$$w_3 = \frac{1}{3!}$$

$$w_4 = -\frac{1}{4!} \qquad (105)$$

$$\cdots.$$

Since

$$W^{(k-2)}(\lambda) = W(\lambda) = \sum_{n=2}^{\infty} \frac{w_{n-2}}{n(n-1)} \lambda^n + A_1\lambda + A_0 \qquad (106)$$

substituting (101), (102), and (105) in (106) yields the result

$$W(\lambda) = -1 + \lambda - \frac{\lambda^2}{2!} + \frac{\lambda^3}{3!} - \frac{\lambda^4}{4!} + \cdots. \qquad (107)$$

The latter equation is recognized as the series expansion for $-e^{-\lambda}$. Hence

$$i(t) = -e^{-t}. \qquad (108)$$

VIII. CONCLUSION AND COMMENTS

This paper has presented a transform method for solving a certain class of ordinary nonlinear differential equations. The method essentially converts a given nonlinear differential equation into a corresponding algebraic equation which can be solved recursively. Under certain conditions, namely, when the general term can be found, the solution can be put in closed form.

It turns out that this method comprises an elegant transform method yielding the same results as the partition method. Actually the method given here is another way of looking at the partition method with a powerful mathematical probe. The Taylor-Cauchy transform is related in a general way to the Mellin-Stieltjes transform.[12,13]

The transform is particularly suited for the analysis of systems with randomly varying inputs.[14] With the transform the randomness is transferred from the continuous functions to discrete functions, thus enabling one to utilize the vast body of material available for the analysis of discrete random processes.

The analysis of linear time-varying systems is also easily handled. It appears that such systems can be analyzed in closed form, or at least an analytic description can be given of the behavior of the stability accurately in the complex frequency plane.

ACKNOWLEDGMENT

The authors wish to acknowledge the support extended them by the National Science Foundation in making these studies in nonlinear-system theory. They also wish to thank Drs. J. G. Brainerd and Harry Sohon for their interest and encouragement in this work.

TABLE I

SOME NONLINEAR CONVOLUTION SUMS

$$1)\ C^{(v)}_{n,k-r} = \sum_{q_{\nu-1}=0}^{n} \cdots \sum_{q_2=0}^{q_3} \sum_{q_1=0}^{q_2} \frac{w_{q_1}}{(q_1+1)(q_1+2)\cdots(q_1+r)} \cdot \frac{w_{q_2-q_1}}{(q_2-q_1+1)(q_2-q_1+2)\cdots(q_2-q_1+r)} \cdots \frac{w_{n-q_{\nu-1}}}{(n-q_{\nu-1}+1)(n-q_{\nu-1}+2)\cdots(n-q_{\nu-1}+r)}$$

$$2)\ C^{(\nu)}_{n-\nu r,k-r} = \sum_{q_{\nu-1}=0}^{n-\nu r} \cdots \sum_{q_2=0}^{q_3} \sum_{q_1=0}^{q_2} \frac{w_{q_1}}{(q_1+1)(q_1+2)\cdots(q_1+r_1)} \cdot \frac{w_{q_2-q_1}}{(q_2-q_1+1)(q_2-q_1+2)\cdots(q_2-q_1+r)} \cdots \frac{w_{n-\nu r-q_{\nu-1}}}{(n-\nu r-q_{\nu-1}+1)(n-\nu r-q_{\nu-1}+2)\cdots(n-\nu r-q_{\nu-1}+r)}$$

$$3)\ C^{(2)}_{n-r_1-r_2,k-r_1,k-r_2} = \sum_{q_1=0}^{n-r_1-r_2} \frac{w_{q_1}}{(q_1+1)(q_1+2)\cdots(q_1+r_1)} \cdot \frac{w_{n-r_1-r_2-q_1}}{(n-r_1-r_2-q_1+1)(n-r_1-r_2-q_1+2)\cdots(n-r_1-q_1)}$$

TABLE II

TAYLOR-CAUCHY TRANSFORM PAIRS—OPERATIONAL FORMS

1	$F(\lambda)$	f_n
2	$F(\lambda)+H(\lambda)$	f_n+h_n
3	$aF(\lambda)$	af_n
4	$\lambda F(\lambda)$	f_{n-1}
5	$\lambda^m F(\lambda)$	f_{n-m}
6	1	$\delta_n = \begin{cases} 1, & n=0 \\ 0, & n\neq 0 \end{cases}$
7	λ	$\delta_{n-1} = \begin{cases} 1, & n=1 \\ 0, & n\neq 1 \end{cases}$
8	λ^m	$\delta_{n-m} = \begin{cases} 1, & n-m \\ 0, & n\neq m \end{cases}$

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[12] A. Erdélyi, *et al.*, "Tables of Integral Transforms," McGraw-Hill Book Co., Inc., New York, N. Y., vol. 2, pp. xi–xii; 1954.

[13] D. V. Widder, "The Laplace Transform," Princeton University Press, Princeton, N. J., pp. 246–247; 1941.

[14] Y. H. Ku and A. A. Wolf, "Transform-ensemble method for analysis of linear and nonlinear systems with random inputs," *Proc. NEC*, vol. 15; March, 1959.

TABLE III

TRANSFORMS—ZERO INITIAL VALUES

1	$W^{(k)}(\lambda)$	w_n	9	$[W^{(k)}(\lambda)]^2$	$C^{(2)}_{n,k}$
2	$W^{(k-1)}(\lambda)$	$\dfrac{w_{n-1}}{n}$	10	$[W^{(k)}(\lambda)]^\nu$	$C^{(\nu)}_{n,k}$
3	$W^{(k-2)}(\lambda)$	$\dfrac{w_{n-2}}{n(n-1)}$	11	$\lambda^m[W^{(k)}(\lambda)]^\nu$	$C^{(\nu)}_{n-m,k}$
4	$W^{(k-r)}(\lambda)$	$\dfrac{w_{n-r}}{n(n-1)\cdots(n-r+1)}$	12	$[W^{(k-1)}(\lambda)]^2$	$C^{(2)}_{n-2,k-1}$
5	$W(\lambda)$	$\dfrac{w_{n-k}}{n(n-1)\cdots(n-k+1)}$	13	$[W^{(k-1)}(\lambda)]^\nu$	$C^{(\nu)}_{n-2\nu,k-1}$
6	$\lambda W^{(k)}(\lambda)$	w_{n-1}	14	$[W^{(k-r)}(\lambda)]^\nu$	$C^{(\nu)}_{n-\nu r,k-r}$
7	$\lambda^m W^{(k)}(\lambda)$	w_{n-m}	15	$[W(\lambda)]^\nu$	$C^{(\nu)}_{n-\nu k,0}$
8	$\lambda^m W^{(k-r)}(\lambda)$	$\dfrac{w_{n-m-r}}{(n-m)(n-m-1)\cdots(n-m-r+1)}$	16	$\lambda^m[W^{(k-r)}(\lambda)]^\nu$	$C^{(\nu)}_{n-m-\nu r,k-r}$
			17	$[W^{(k-r_1)}(\lambda)][W^{(k-r_2)}(\lambda)]$	$C^{(2)}_{n-r_1-r_2,k-r_1,k-r_2}$
			18	$\lambda^m[W^{(k-r_1)}(\lambda)]$ $\cdot[W^{(k-r_2)}(\lambda)]$	$C^{(2)}_{n-m-r_1-r_2,k-r_1,k-r_2}$

TABLE IV

TRANSFORMS—NONZERO INITIAL CONDITIONS

1	$W^{(k-1)}(\lambda)$	$\dfrac{w_{n-1,k}}{n}+A_{k-1}\delta_n$
2	$W^{(k-2)}(\lambda)$	$\dfrac{w_{n-2,k}}{n(n-1)}+A_{k-1}\delta_{n-1}+A_{k-2}\delta_n$
3	$W^{(k-r)}(\lambda)$	$\dfrac{w_{n-r,k}}{n(n-1)\cdots(n-r+1)}+\sum_{q=1}^{r}\dfrac{A_{k-q}}{(k-q)!}\delta_{n-r+q}$
4	$W(\lambda)$	$\dfrac{w_{n-k,k}}{n(n-1)\cdots(n-k+1)}+\sum_{q=1}^{k}\dfrac{A_{k-q}}{(k-q)!}\delta_{n-k+q}$
5	$\lambda^m W^{(k-r)}(\lambda)$	$\dfrac{w_{n-m-r,k}}{(n-m)(n-m-1)\cdots(n-m-r+1)}+\sum_{q=1}^{r}\dfrac{A_{k-q}}{(r-q)!}\delta_{n-m-r+q}$
6	$[W^{(k-r)}(\lambda)]^\nu$	$C_{n-\nu r,k-r}+\sum_{i=1}^{\nu-1}\sum_{q=1}^{r}\binom{\nu}{i}C^{(\nu-i)}_{n-(\nu-i+1)r-q}A^{(i)}_{r-q}+\sum_{q=1}^{r}A^{(\nu)}_{r-q}\delta_{n-r+q}$
		in which $A^{(i)}_{r-q}$ and $A^{(\nu)}_{r-q}$ are defined generally by
		$A^{(j)}_{r-q}=\sum_{s_{j-1}=0}^{r-q}\cdots\sum_{s_2=0}^{s_3}\sum_{s_1=0}^{s_2}\dfrac{A_{k+s_1-r}}{s_1!}\cdot\dfrac{A_{k+s_2-s_1-r}}{(s_2-s_1)!}\cdots\dfrac{A_{k-s_{j-1}-q}}{(r-q-s_j-1)!}$
7	$\lambda^m[W^{(k-r)}(\lambda)]^\nu$	$C_{n-m-\nu r,k-r}+\sum_{i=1}^{\nu-1}\sum_{q=1}^{r}\binom{\nu}{i}C_{n-m-(\nu-i+1)r-q}A^{(i)}_{r-q}+\sum_{q=1}^{r}A^{(\nu)}_{r-q}\delta_{n-m-r+q}$
8	$[W^{(k-r_1)}(\lambda)][W^{k-r_2}(\lambda)]$	$C^{(2)}_{n-r_1-r_2,k-r_1,k-r_2}+\sum_{q=1}^{r_2}\dfrac{A_{k-q}}{(r_2-q)!}\dfrac{w_{n-r_1-r_2+q,k}}{(n-r_1-r_2+q+1)(n-r_1-r_2+q+2)\cdots(n-r_2+q)}$
		$+\sum_{q=1}^{r_1}\dfrac{A_{k-q}}{(r_1-q)!}\dfrac{w_{n-r_1-r_2+q,k}}{(n-r_1-r_2+q+1)(n-r_1-r_2+q+2)\cdots(n-r_1+q)}+\sum_{m=0}^{r_1+r_2-2}A^{(2)}_{m,r_1,r_2}\delta_{n-m}$
		in which
		$A_{m,r_1,r_2}=\sum_{s=0}^{r_1-1}\dfrac{A_{k+s-r_1}}{s!}\cdot\dfrac{A_{k+n-s-r}}{(n-s)!}$
9	$e^{\alpha\lambda}$	$\dfrac{(\alpha)^n}{n!}$
10	$\sin\beta\lambda$	$\dfrac{(-1)^n(\beta)^{2n-1}}{(2n+1)!}$
11	$\cos\beta\lambda$	$\dfrac{(-1)^n(\beta)^{2n}}{(2n)!}$
12	$e^{\alpha\lambda}\sin\beta\lambda$	$\sum_{k=0}^{n}\dfrac{(-1)^k\beta^{2k+1}}{(2k+1)!}\cdot\dfrac{\alpha^{n-k}}{(n-k)!}$
13	$e^{\alpha\lambda}\cos\beta\lambda$	$\sum_{k=0}^{n}\dfrac{(-1)^k\beta^{2k}}{(2k)!}\cdot\dfrac{\alpha^{n-k}}{(n-k)!}$
14	$\sum_{n=0}^{\infty}a_n\lambda^n$	a_n
15	$\dfrac{1}{1-\alpha\lambda}$	α^n
16	$\dfrac{1-(\alpha\lambda)^{m+1}}{1-\alpha\lambda}$	$\begin{cases}\alpha^n, & n\le m\\ 0, & n>m\end{cases}$

Laurent-Cauchy Transforms for Analysis of Linear Systems Described by Differential-Difference and Sum Equations[*]

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Summary—**The Taylor-Cauchy transform for the analysis of nonlinear systems was presented at the 1959 IRE National Convention.[1] In this paper it is shown that the Laurent-Cauchy transform can be derived from the Taylor-Cauchy transform by a simple mapping. Whereas a complex λ plane is used in the Taylor-Cauchy transform, a complex ρ plane is used in the Laurent-Cauchy transform where the two complex variables are related by $\lambda = 1/\rho$. In the Taylor-Cauchy transform method, $W^{(k)}(\lambda)$, the kth derivative of $W(\lambda)$, converges inside a circle. However, in the Laurent-Cauchy transform method, $H(\rho)$ converges outside of a circle of radius R. Thus, $W^{(k)}(\lambda)$ is expressible by a Taylor series whose general term is**

$$\sum_{n=0}^{\infty} w_{n,k}\lambda^{n}$$

and $H(\rho)$ is expressible by a Laurent series whose general term is

$$\sum_{n=0}^{\infty} h_{n}\rho^{-n}.$$

In either case, the relation between the coefficients of the power series and the function of a complex variable is given by Cauchy's integral. In conjunction with the Laplace transform, the Laurent-Cauchy transform can be used to analyze discrete-continuous systems such as digital servomechanisms, retarded feedback control systems, certain analog-digital computer systems, and pulsed-data systems. If n is replaced by nT, where T is a sampling time, and h_n is taken to mean $h(nT)$, the Laurent-Cauchy transform reduces to the Z-transform. A table of Laurent-Cauchy transforms, several theorems, and three examples are given in the paper.

I. INTRODUCTION

IN a previous work[1] a transform method, the Taylor-Cauchy transform, was developed as a formal consequence of a mathematical theory for analysis of nonlinear systems.[2–5] The Taylor-Cauchy transform method was presented at the 1959 IRE National Convention, and now appears as a companion paper in this issue. This method, the Taylor-Cauchy transform, is one member of a broad class of transforms which correspond to a given class of generalized or modified forcing functions. Another member of this class of transforms is developed in this paper. The new transform method, the Laurent-Cauchy transform, can be derived from the Taylor-Cauchy transform by a simple mapping. A new complex variable ρ, used in the Laurent-Cauchy transform, is related to the complex variable λ, used in the Taylor-Cauchy transform, by the simple relation $\lambda = 1/\rho$. In the Taylor-Cauchy transform method, $W^{(k)}(\lambda)$, the kth derivative of $W(\lambda)$, converges inside a circle. In the Laurent-Cauchy transform method, $H(\rho)$, a function of the complex variable ρ, converges outside a circle of radius R. Thus $W^{(k)}(\lambda)$ is expressible by a Taylor series whose general term is

$$\sum_{n=0}^{\infty} w_{n,k}\lambda^{n}$$

whereas $H(\rho)$ is expressible by a Laurent series whose general term is

$$\sum_{n=0}^{\infty} h_{n}\rho^{-n}.$$

Just as $w_{n,k}$ is related to $W^{(k)}(\lambda)$ by the Cauchy integral, so it is shown that h_n is related to $H(\rho)$ by the Cauchy integral with a different contour.

The Laurent-Cauchy transform is particularly useful in the analysis of physical systems described by differential-difference and sum equations. Used in conjunction with the Laplace transform, it makes possible the analysis of discrete-continuous systems such as digital servomechanisms, retarded feedback control systems, certain analog-digital computer systems, and pulsed-data systems. In addition, if the input is a random process, the Laurent-Cauchy transform can be used with the transform-ensemble method[6] to obtain information about the statistics of the response of the discrete systems.

II. DERIVATION OF THE LAURENT-CAUCHY TRANSFORM FROM THE TAYLOR-CAUCHY TRANSFORM

The Taylor-Cauchy transform pair[1] is given by (1) and (2) below:

$$w_{n,k} = \frac{1}{2\pi j}\int_{C'} \frac{W^{(k)}(\lambda)}{\lambda^{n+1}}\, d\lambda \tag{1}$$

$$W^{(k)}(\lambda) = \sum_{n=0}^{\infty} w_{n,k}\lambda^{n} \tag{2}$$

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[*] Original manuscript received by the IRE, May 25, 1959; revised manuscript received, December 11, 1959. This work was done under a research grant from the National Science Foundation.

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[1] Y. H. Ku, A. A. Wolf, and J. H. Dietz, "Taylor-Cauchy transforms for the analysis of a certain class of nonlinear systems," this issue, pp. 912–922. See also 1959 IRE NATIONAL CONVENTION RECORD, pt. 2, pp. 49–61.

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[6] Y. H. Ku and A. A. Wolf, "Transform-ensemble method for analysis of linear and nonlinear systems with random inputs," *Proc. NEC*, vol. 15; March, 1959.

where

$w_{n,k}$ denotes the direct Taylor-Cauchy transform of $W^{(k)}(\lambda)$,

$W^{(k)}(\lambda)$ denotes the kth derivative of a complex time function $W(\lambda)$,

$W(\lambda)$ denotes a function of the complex variable λ corresponding to a function of the real time variable t,

n denotes the real discrete variable in the transform half-line corresponding to the complex time variable λ in the complex time plane,

λ denotes a complex time variable corresponding to the real time variable t, and

C' denotes a contour in the λ-plane defining the domain of definition of the complex time function $W(\lambda)$ and enclosing the singularities of the integrand of (1).

Consider now the transformation given below:

$$\lambda = \frac{1}{\rho} \tag{3}$$

where ρ defines a complex frequency variable in the complex ρ-plane. Eq. (3) is a bilinear transformation with the property that points inside the unit circle in the λ-plane map into corresponding points outside the unit circle in the ρ-plane. The differential of λ is given by

$$d\lambda = -\frac{d\rho}{\rho^2}\cdot \tag{4}$$

Substituting (3) and (4) into (1) and (2) yields

$$w_{n,k} = \frac{1}{2\pi j}\int_C W^{(k)}\left(\frac{1}{\rho}\right)\rho^{n-1}d\rho \tag{5}$$

and

$$W^{(k)}\left(\frac{1}{\rho}\right) = \sum_{n=0}^{\infty} w_{n,k}\rho^{-n}. \tag{6}$$

Let us denote $w_{n,k}$ by $h_{n,q}$ and $W^{(k)}(1/\rho)$ by $H^{(q)}(\rho)$ respectively. Thus

$$h_{n,q} = w_{n,k} \tag{7}$$

$$H^{(q)}(\rho) = W^{(k)}\left(\frac{1}{\rho}\right). \tag{8}$$

Thus, we may write (5) and (6) as

$$h_{n,q} = \frac{1}{2\pi j}\int_C H^{(q)}(\rho)\rho^{n-1}d\rho \tag{9}$$

$$H^{(q)}(\rho) = \sum_{n=0}^{\infty} h_{n,q}\rho^{-n}. \tag{10}$$

The nature and restrictions concerning the functions h_n and $H(\rho)$ are discussed in Section III. The contour C encloses the singularities of $H^{(q)}(\rho)\rho^{n-1}$ corresponding to the contour C' by means of the mapping given in (3). The index q in (8) can be omitted in practical cases. Formally, the index q may denote the qth derivative of $H(\rho)$ with respect to ρ. We allow q to be different from k so that (11) is satisfied:

$$0 \leq q \leq k. \tag{11}$$

For certain applications such as differential-difference and sum equations we have h_n and $H(\rho)$ as functions of time t, a real variable. Thus, after dropping q and introducing t explicitly, we get

$$h_n(t) = \frac{1}{2\pi j}\int_C H(\rho, t)\rho^{n-1}d\rho \tag{12}$$

$$H(\rho, t) = \sum_{n=0}^{\infty} h_n(t)\rho^{-n}. \tag{13}$$

As functions of a real variable t, $h_n(t)$ and $H(\rho, t)$ in (12) and (13) are Laplace transformable. For the sake of clarity, we may keep the symbols h_n and $H(\rho)$ to represent the Laurent-Cauchy transform pairs, irrespective of whether h_n and $H(\rho)$ are functions of t or of their Laplace transforms.

In Table I (Appendix I), q is taken as zero as in (12) and (13). Furthermore, we shall omit t, understanding its presence implicitly. The implication of this selection and other geometric interpretations are given in a note[7] previously published.

III. RESTRICTIONS ON THE FUNCTIONS AND NOTATION

In this section we shall briefly discuss some of the pertinent restrictions on the functions h_n and $H(\rho)$. Let us now rewrite (12) and (13) consistent with the conditions of the last paragraph:

$$h_n = \frac{1}{2\pi j}\int_C H(\rho)\rho^{n-1}d\rho \tag{14}$$

$$H(\rho) = \sum_{n=0}^{\infty} h_n\rho^{-n}. \tag{15}$$

We make the following assumptions.

1) $$h_m = O(r^m) \tag{16}$$

where $r>R>O$, $r=|\rho|$, and

$$R^{-1} = \limsup_{n\to\infty} |h_n|^{1/n}. \tag{17}$$

R is the radius of a circle in the complex ρ-plane outside of which the series of (15) converges.

2) If $h_n = h_n(t)$, then

$$h_n(t) = O(e^{\alpha_n t});\ \alpha_n \text{ constant for each } n. \tag{18}$$

3) $H(\rho)$ converges outside of a circle of radius R.

4) If $H(\rho) = H(\rho, t)$, then

$$H(\rho, t) = O(e^{\beta_\rho t});\quad \beta_\rho \text{ constant for each } \rho. \tag{19}$$

5) The contour C is determined from (17) and (20):

$$\rho = re^{j\theta} \tag{20}$$

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[7] A. A. Wolf, "On the significance of transients and steady-state behavior in nonlinear systems," PROC. IRE, vol. 47, pp. 1785–1786; October, 1959.

where θ is the angle of direction in the ρ-plane with the center of the circle at the origin, and r is the magnitude of ρ.

We note that (15) can be considered as a means of transforming a function of a discrete variable, h_n, into a continuous function of a complex frequency variable, $H(\rho)$. This mapping is illustrated in Fig. 1.

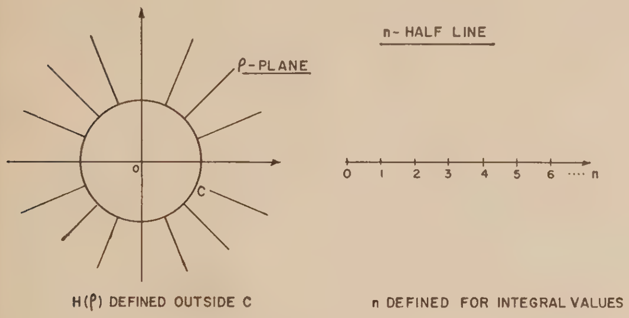

Fig. 1—Mapping of Laurent-Cauchy transform.

IV. APPLICATION OF THE LAURENT-CAUCHY TRANSFORM METHOD

Let us denote the direct Laurent-Cauchy transform and its inverse by the symbols $\mathcal{L}_c$ and $\mathcal{L}_c^{-1}$, respectively. We choose (15) to define $H(\rho)$ as the direct Laurent-Cauchy transform of h_n such that

$$\mathcal{L}_c[h_n] = H(\rho). \tag{21}$$

This is similar to the symbolic relation in Laplace transforms: $\mathcal{L}[y(t)] = Y(s)$, where $y(t)$ is a function of the real variable t and $Y(s)$ is a corresponding function of the complex variable s. The inverse Laurent-Cauchy transform is then defined by (14) and expressed symbolically by (22):

$$\mathcal{L}_c^{-1}[H(\rho)] = h_n. \tag{22}$$

Comparing (14) with the well-known complex integral form of $\mathcal{L}^{-1}[Y(s)]$, we see that in both cases the inverse transform can be obtained by contour integration. Thus, we may consider both the Laurent-Cauchy transform and the Laplace transform (as well as the Fourier transform) as members of a general class of transforms. It is logical to ask whether the Z-transform also belongs to this general class. If n is replaced by nT, where T is a sampling time, and the discrete variable h_n is taken to mean $h(nT)$, we see that (12) and (13) reduce to the Z-transform.

Difference equations are used to approximate the differential equations that describe a continuous system. Mixed difference-differential equations are sometimes encountered. Here we shall consider a more general form given by (23) which may be termed a differential-difference and sum equation:

$$\sum_{m=0}^{M}\sum_{k=0}^{K}\alpha_{km}y_{n+m}^{(k)}(t) + \sum_{k=0}^{n}\beta_k y_k(t) = x_n(t). \tag{23}$$

We desire to determine $y_n(t)$ in terms of α's, β's and the forcing function $x_n(t)$. Note that $y_n^{(k)}(t)$ denotes the kth derivative of $y_n(t)$ with respect to time. An equation like (23) could describe a pulsed data or retarded feedback control system. Letting the Laplace transforms of $y_n(t)$ and $x_n(t)$ be denoted by $h_n(s)$ and $g_n(s)$, respectively,

$$h_n(s) = Y_n(s) = \mathcal{L}[y_n(t)];\ g_n(s) = X_n(s) = \mathcal{L}[x_n(t)]. \tag{24}$$

The Laurent-Cauchy pairs can be given as follows, similar to (12) and (13):

$$h_n(s) = \frac{1}{2\pi j}\int_C H(\rho, s)\rho^{n-1}d\rho \tag{25}$$

$$H(\rho, s) = \sum_{n=0}^{\infty} h_n(s)\rho^{-n}. \tag{26}$$

Similar pairs can be given for $g_n(s)$ and $G(\rho, s)$. Assuming that the system is initially at rest and noting that the Laplace transform of $y_{n+m}^{(k)}(t)$ equals $s^k h_{n+m}(s)$, we apply first the Laplace transform and then the Laurent-Cauchy transform to (23) to give

$$\sum_{m=0}^{M}\sum_{k=0}^{K}\alpha_{km}s^k\mathcal{L}_c[h_{n+m}(s)] + \mathcal{L}_c\left[\sum_{k=0}^{n}\beta_k h_k(s)\right] = \mathcal{L}_c[g_n(s)]. \tag{27}$$

From (26) and Appendix I, we have

$$\mathcal{L}_c[h_n(s)] = H(\rho, s) \tag{28}$$

$$\mathcal{L}_c[h_{n+m}(s)] = \rho^m H(\rho, s) \tag{29}$$

$$\mathcal{L}_c[g_n(s)] = G(\rho, s). \tag{30}$$

In Section VI it is shown that

$$\mathcal{L}_c\left[\sum_{k=0}^{n}\beta_k h_k(s)\right] = \left(\frac{\rho}{\rho - 1}\right)\frac{1}{2\pi j}\int_C \frac{B(\gamma)H\left(\dfrac{\rho}{\gamma}, s\right)}{\gamma}d\gamma \tag{31}$$

where γ denotes a complex variable like ρ, and $B(\gamma)$ is the Laurent-Cauchy transform of β_k. On utilizing (28), (29), (30), and (31) we obtain from (27) the transform equations in ρ and s as follows:

$$H(\rho, s)\sum_{m=0}^{M}\sum_{k=0}^{K}\alpha_{km}s^k\rho^m + \frac{\rho}{\rho - 1}\,\frac{1}{2\pi j}\int_C \frac{B(\gamma)H\left(\dfrac{\rho}{\gamma}, s\right)}{\gamma}d\gamma = G(\rho, s). \tag{32}$$

Eq. (32) is a linear integral equation of the kind which may be solved by a convergent iteration process.[1,2] The general solution of (32) in terms of the elementary functions is not known. Let us examine a special case in which $\beta_k = \beta$ for all $k \geq 0$, where β is a constant. With this condition, (32) simplifies to

$$H(\rho, s)\sum_{m=0}^{M}\sum_{k=0}^{K}\alpha_{km}s^k\rho^m + \frac{\rho\beta}{\rho-1}H(\rho, s) = G(\rho, s). \quad (33)$$

Therefore

$$H(\rho, s) = \frac{G(\rho, s)}{D(\rho, s)} \quad (34)$$

where

$$D(\rho, s) = \sum_{m=0}^{M}\sum_{k=0}^{K}\alpha_{km}s^k\rho^m + \frac{\rho\beta}{\rho-1}\cdot \quad (35)$$

To recover $y_n(t)$, it is necessary first to have a knowledge of the zeros of $D(\rho,s)$ given by (35). Knowing the zeros of $D(\rho, s)$, the residue theorem can be applied first to the inverse Laplace transform and then to the inverse Laurent-Cauchy transform. Formally, this gives

$$y_n(t) = \mathcal{L}_c^{-1}\mathcal{L}^{-1}[H(\rho, s)] = \mathcal{L}^{-1}\mathcal{L}_c^{-1}[H(\rho, s)]. \quad (36)$$

The operators $\mathcal{L}^{-1}$ and $\mathcal{L}_c^{-1}$ are commutative with respect to the operand. In complicated cases the roots of s might involve radicals of the variable ρ and conversely. Thus, higher order singularities may lead to branch points and the solution may then involve transcendental functions of higher order.

V. COMPUTER CONTROLLED FEEDBACK SYSTEM

To illustrate the use of (12), (13), (25) and (26), let us consider an example involving continuous-discrete processes. Referring to Fig. 2, a simple servo is controlled by a computer (shown in Fig. 3) so that its output is suitably modulated. It is possible in this system to separate the continuous process from the discrete process. This is equivalent to saying mathematically that the difference equation is separate from the continuous equation. In such cases, the total solution is usually the product of the separate solutions. In other words, one process amplitude modulates the other. To illustrate the present method, no notice will be made of the separability property from the system configuration. Instead, we shall solve this as a mathematical problem.

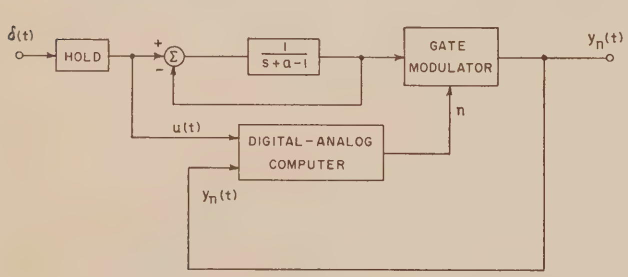

Fig. 2—An exponential pulse response feedback computer control system.

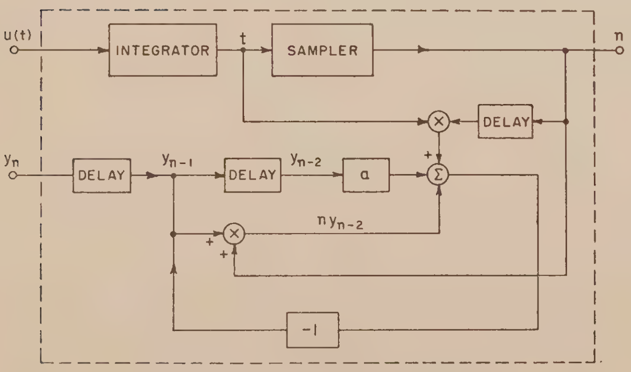

Fig. 3—Digital-analog computer of Fig. 2.

Example 1: Consider the equation

$$y'_{n+1}(t) + \frac{a}{n+1}y_n(t) = 0 \quad (37)$$

where the prime denotes a time derivative, a denotes a constant, and n denotes gate-time pulses taking the discrete values $n=0, 1, 2, \cdots$ only. The initial conditions are

$$y_n(0) = \frac{1}{n!}\cdot \quad (38)$$

Eq. (37) can be rewritten as

$$(n+1)y'_{n+1}(t) + ay_n(t) = 0. \quad (39)$$

Taking the Laplace transform gives

$$\begin{aligned}(n+1)sY_{n+1}(s) + aY_n(s) &= (n+1)y_{n+1}(0)\\ &= \frac{(n+1)}{(n+1)!} = \frac{1}{n!}\cdot \quad (40)\end{aligned}$$

Denoting $Y_n(s)$ by $h_n(s)$ as in (24) and noting $Y_{n+1}(s) = h_{n+1}(s)$, (40) becomes

$$s(n+1)h_{n+1}(s) + ah_n(s) = \frac{1}{n!}\cdot \quad (40a)$$

From Table I (Appendix I) we get

$$\mathcal{L}_c[(n+1)h_{n+1}] = -\rho^2H'(\rho) \quad (41)$$

where $H'(\rho) = dH(\rho)/d\rho$:

$$\mathcal{L}_c\left[\frac{1}{n!}\right] = e^{1/\rho}. \quad (42)$$

Taking the Laurent-Cauchy transform of (40) and utilizing the results of (28), (41) and (42), we get the transform equation

$$-s[\rho^2H'(\rho, s)] + aH(\rho, s) = e^{1/\rho}. \quad (43)$$

Solving for $H(\rho, s)$ gives

$$H(\rho, s) = \frac{e^{1/\rho}}{s+a}\cdot \quad (44)$$

The correctness of the above solution can be checked by noting that $dH/d\rho = (-1/\rho^2)H$ and that the left-hand terms of (43) add up to $(s+a)H(\rho, s)$. Inverting (44) with respect to ρ gives

$$h_n(s) = \frac{1}{n!(s+a)}\cdot \tag{45}$$

Noting that $h_n(s)=Y_n(s)$, according to (24), and taking the inverse Laplace transform, gives

$$y_n(t) = \frac{e^{-at}}{n!}\cdot \tag{46}$$

Eq. (46) signifies a sequence of functions defined for discrete values of $n=0, 1, 2, \cdots$ so that

$$y_0(t) = e^{-at};\ y_1(t) = e^{-at};\ y_2(t) = \frac{e^{-at}}{2};\cdots. \tag{47}$$

Eq. (47) gives the values for the interval corresponding to n. Thus, $y_0(t)$ defines the value for the interval 0 to 1, $y_1(t)$ defines the value for the interval 1 to 2, $y_2(t)$ defines the value for the interval 2 to 3, and so on. The physical implications of such systems will not be discussed here except to say that phenomena exist which decay rapidly with time. Then, a system of pulses which also decay rapidly with time may be useful as a timing reference.

From the above example, we see that by using both the Laplace transform and the Laurent-Cauchy transform we are able to separate the two processes, one continuous and one discrete. The final answer is then found to be the product of the two separate solutions.

VI. DERIVATION OF PRODUCT AND SUM TRANSFORMS

Transform of Sum of Sequence Functions

In certain physical applications it is required to sum a set of n-sequence functions as shown in Fig. 4. A knowledge of the transform of the sum is therefore necessary. Such a sum appears in (23) and its transform is given in (31) and (32). We now show details of obtaining this transform. By definition, as given in (15),

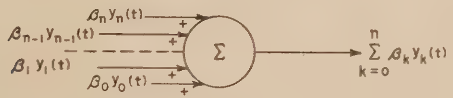

Fig. 4—Summation of time sequence functions.

$$\mathfrak{L}_c\left[\sum_{k=0}^{n}\beta_k h_k(s)\right] = \sum_{n=0}^{\infty}\sum_{k=0}^{n}\beta_k h_k(s)\rho^{-n}. \tag{48}$$

The right-hand member of (48) may be written as

$$\sum_{k=0}^{\infty}\sum_{n=k}^{\infty}\beta_k h_k(s)\rho^{-n}$$

by interchanging the order of summation. Thus (48) becomes

$$\mathfrak{L}_c\left[\sum_{k=0}^{n}\beta_k h_k(s)\right] = \sum_{k=0}^{\infty}\beta_k h_k(s)\sum_{n=k}^{\infty}\rho^{-n}. \tag{49}$$

Now

$$\sum_{n=k}^{\infty}\rho^{-n} = \frac{\rho^{-k}}{1-\rho^{-1}} = \frac{\rho}{\rho-1}\rho^{-k}. \tag{50}$$

Substituting (50) into (49) gives

$$\mathfrak{L}_c\left[\sum_{k=0}^{n}\beta_k h_k(s)\right] = \frac{\rho}{\rho-1}\sum_{k=0}^{\infty}\beta_k h_k(s)\rho^{-k} \tag{51}$$

$$= \frac{\rho}{\rho-1}\mathfrak{L}_c[\beta_k h_k(s)]. \tag{51a}$$

The right-hand member of (51a) is reduced by use of

$$\beta_k = \frac{1}{2\pi j}\int_C B(\gamma)\gamma^{k-1}d\gamma \tag{52}$$

where γ is a complex variable like ρ. Thus

$$\mathfrak{L}_c[\beta_k h_k(s)] = \sum_{k=0}^{\infty}\left[\frac{1}{2\pi j}\int_C B(\gamma)\gamma^{k-1}d\gamma\right]h_k(s)\rho^{-k} \tag{53}$$

$$= \frac{1}{2\pi j}\int_C B(\gamma)\gamma^{-1}\left[\sum_{k=0}^{\infty}h_k(s)\left(\frac{\rho}{\gamma}\right)^{-k}\right]d\gamma. \tag{54}$$

But by definition, as given in (15), we have

$$H\left(\frac{\rho}{\gamma}, s\right) = \sum_{k=0}^{\infty}h_k(s)\left(\frac{\rho}{\gamma}\right)^{-k}. \tag{55}$$

Substituting (55) into (54) and this result into (51a) gives

$$\mathfrak{L}_c\left[\sum_{k=0}^{n}\beta_k h_k(s)\right]$$

$$= \frac{\rho}{\rho-1}\frac{1}{2\pi j}\int_C B(\gamma)\gamma^{-1}H\left[\frac{\rho}{\gamma}, s\right]d\gamma. \tag{56}$$

Eq. (56) is the same as (31) and is the transform of a sum of sequence functions.

Special Case of the Sum of Sequence Functions

Consider a special case of (56), namely, when $\beta_k=\beta$ for all values of k greater or equal to zero. Since β is a constant, we may remove β from under the summation sign. Therefore, we have

$$\mathfrak{L}_c\left[\beta\sum_{k=0}^{n}h_k(s)\right] = \frac{\rho\beta}{\rho-1}\sum_{k=0}^{\infty}h_k(s)\rho^{-k}. \tag{57}$$

Since

$$H(\rho, s) = \sum_{k=0}^{n}h_k(s)\rho^{-k}, \tag{58}$$

substitution of (58) into (57) gives

$$\mathcal{L}_c\left[\beta\sum_{k=0}^{\infty}h_k(s)\right]=\frac{\rho\beta}{\rho-1}H(\rho,s). \tag{59}$$

A number of other transforms appear in Table I on pages 930 and 931. In the table, the variable t is often understood and does not appear explicitly.

VII. SUMMATION THEOREMS

The Laurent-Cauchy transform is very useful in summing certain series, examples of which are

$$\sum_{n=0}^{\infty} f_n, \tag{60}$$

$$\sum_{n=0}^{\infty} f_n y_n, \tag{61}$$

$$\sum_{n=0}^{k} f_n, \tag{62}$$

etc.

The problem of summing such series in a general way has been the subject of works of many prominent mathematicians.[8] We shall show how the following theorems are obtained.

First Summation Theorem

Given a discrete function f_n whose Laurent-Cauchy transform $F(\rho)$ is known. Then

$$\sum_{n=0}^{\infty} f_n=\frac{1}{2\pi j}\int_C \frac{F(\rho)}{\rho(1-\rho)}\,d\rho. \tag{63}$$

Proof: Since

$$f_n=\frac{1}{2\pi j}\int_C F(\rho)\rho^{n-1}d\rho \tag{64}$$

then as

$$\sum_{n=0}^{\infty} f_n=\frac{1}{2\pi j}\int_C F(\rho)\sum_{n=0}^{\infty}\rho^{n-1}d\rho \tag{65}$$

utilizing the summation formula

$$\sum_{n=0}^{\infty}\rho^{n-1}=\rho^{-1}\frac{1}{1-\rho}; \qquad |\rho|<1 \tag{66}$$

we obtain (63).

Second Summation Theorem

Given a discrete function f_n whose $\mathcal{L}_c$-transform is $F(\rho)$. Then

$$\sum_{n=0}^{k} f_n=\frac{1}{2\pi j}\int_C \frac{F(\rho)(1-\rho^{k+1})}{\rho(1-\rho)}\,d\rho. \tag{67}$$

The proof follows a pattern similar to the previous theorem.

Third Summation Theorem

Given two $\mathcal{L}_c$-transformable discrete functions f_n and y_n with $\mathcal{L}_c$-transforms $F(\rho)$ and $Y(\rho)$, then

$$\sum_{n=0}^{\infty} f_n y_n=\frac{1}{2\pi j}\int_C \rho^{-1}F(\rho^{-1})Y(\rho)d\rho. \tag{68}$$

Proof: Let

$$y_n=\frac{1}{2\pi j}\int_{C_1} Y(\rho)\rho^{n-1}d\rho \tag{69}$$

and f_n is defined as before with a contour C_2. Let $C=C_1+C_2$, then

$$y_n f_n=\frac{1}{2\pi j}\int_C Y(\rho)\rho^{n-1}f_n d\rho. \tag{70}$$

Summing both sides of (70) yields

$$\sum_{n=0}^{\infty} y_n f_n=\frac{1}{2\pi j}\int_C Y(\rho)\sum_{n=0}^{\infty}\rho^{n-1}f_n d\rho; \tag{71}$$

utilizing

$$\sum_{n=0}^{\infty} f_n\rho^n=F(\rho^{-1}) \tag{72}$$

we obtain the theorem given in (68).

Other Summation Theorems

We state here the results of two other summation theorems:

$$\sum_{n=0}^{\infty} y_{n+1}\Delta f_n=\frac{1}{2\pi j}\int_C Y(\rho)F(\rho^{-1})\frac{1-\rho}{\rho}\,d\rho \tag{73}$$

and

$$\sum_{n=0}^{\infty} y_n\Delta f_n=\frac{1}{2\pi j}\int_C Y(\rho)F(\rho^{-1})\frac{1-\rho}{\rho^2}\,d\rho \tag{74}$$

where

$$\Delta f_n=f_{n+1}-f_n. \tag{74a}$$

VIII. EXAMPLES

To illustrate some of the above theorems we shall consider the following examples.

Example 2—A Simple Sum: Given $f_n=n$

$$f_n=n \tag{75}$$

$$F(\rho)=\frac{\rho}{(\rho-1)^2}, \tag{76}$$

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[8] G. Boole, "A Treatise on the Calculus of Finite Differences," G. E. Stechert and Co., New York, N. Y.; 1860.

thus

$$\sum_{n=0}^{k} n = \frac{1}{2\pi j}\int_C \frac{\rho(1-\rho^{k+1})}{(1-\rho)^2(1-\rho)\rho}\,d\rho. \tag{77}$$

Simplifying (77),

$$\sum_{n=0}^{k} n = \frac{1}{2!}\,\frac{d^2}{d\rho^2}\left[\rho^{k-1}-1\right]_{\rho=1} \tag{78}$$

$$\sum_{n=0}^{k} n = \frac{k(k+1)}{2}\,. \tag{79}$$

This result checks the well-known result for this sum.

Example 3—A Simple Product Sum: Consider

$$y_n = a^n \tag{80}$$

$$Y(\rho) = \frac{\rho}{\rho - a} \tag{81}$$

and

$$f_n = \frac{1}{n!} \tag{82}$$

$$F(\rho) = e^{1/\rho} \tag{83}$$

$$F\left(\frac{1}{\rho}\right) = e^{\rho}. \tag{84}$$

Then

$$\sum_{n=0}^{\infty} \frac{a^n}{n!} = \frac{1}{2\pi j}\int_C \rho^{-1}\,\frac{\rho}{\rho-a}\,e^{\rho}d\rho \tag{85}$$

$$= \frac{1}{2\pi j}\int_C \frac{e^{\rho}}{\rho-a}\,d\rho \tag{86}$$

$$= e^{a}. \tag{87}$$

Eq. (87) is known to be correct. The correspondence is evident upon expanding e^a by a Taylor series.

IX. COMPARISON OF LAURENT-CAUCHY AND TAYLOR-CAUCHY TRANSFORMS

The Taylor-Cauchy transform is one member of a general class of transforms useful in the analysis of certain physical systems. It is useful in the analysis of nonlinear systems. The direct Taylor-Cauchy transform is defined by (1) and can be symbolically expressed as

$$\mathfrak{T}_c\left[W^{(k)}(\lambda)\right] = w_{n,k}. \tag{88}$$

The inverse Taylor-Cauchy transform is defined by (2) and can be symbolically expressed as

$$\mathfrak{T}_c^{-1}\left[w_{n,k}\right] = W^{(k)}(\lambda). \tag{89}$$

Thus, the direct Taylor-Cauchy transform is defined by Cauchy's integral, whereas its inverse is given in the form of a Taylor series, the summation of $w_{n,k}\lambda^n$.

The Laurent-Cauchy transform is another member of a general class of transforms. It is useful in the analysis of systems involving discrete processes, whereas the Taylor-Cauchy transform deals with continuous nonlinear processes. The direct Laurent-Cauchy transform is defined by (21), where the left-hand member represents symbolically the summation of $h_n\rho^{-n}$, which has the form of a Laurent series. On the other hand, the inverse transform defined by (22) takes the form of Cauchy's integral given in (14). Thus, not only are the two complex variables reciprocals of each other as defined in (3), the complex contour integral (1) defines the direct transform in the case of the Taylor-Cauchy transform, whereas the complex contour integral (14) defines the inverse transform in the case of the Laurent-Cauchy transform. In the Taylor-Cauchy transform method, $W^{(k)}(\lambda)$, the kth derivative of $W(\lambda)$, converges inside a circle. In the Laurent-Cauchy transform method, $H(\rho)$ converges outside a circle of radius R defined in connection with (16) and (17). Although both the Laurent-Cauchy and Taylor-Cauchy transforms belong to a general class of transforms, each has a realm of usefulness in the analysis of physical systems.

X. CONCLUSION AND DISCUSSION

This paper has presented some aspects of a discrete-to-continuous transform method for analyzing certain linear systems. Since the use of sequence functions reduces the labor in solving problems arising in the analysis of systems which are modulated in some manner, the Laurent-Cauchy transform is useful. In addition, if t is fixed, we can solve sum-difference equations and evaluate the sum of certain series which are $\mathfrak{L}_c$-transformable. Further, if n is considered as a discrete time variable, we can solve equations representing retarded feedback control systems such as a difference frequency AFC.[9] In the latter connection, if n is replaced by nT, where T is a sampling time, and the discrete variable h_n is taken to mean $h(nT)$, we see that (12) and (13) reduce to the Z-transform.[10–12] If the input to a given discrete system is random, the Laurent-Cauchy transform can be used in the transform-ensemble method in determining the response of the system statistically.[6]

XI. ACKNOWLEDGMENT

The authors wish to acknowledge the support extended them by the National Science Foundation in making these studies on nonlinear theory and related fields, and the encouragement of Dr. J. G. Brainerd. Thanks are also due to Dr. R. Weller and K. Lord of the Stromberg-Carlson Company.

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[9] A. A. Wolf, "A Mathematical Theory of AFC," M. S. thesis, The Moore School of Electrical Engineering, University of Pennsylvania, Philadelphia; 1954.

[10] J. R. Ragazzini and L. A. Zadeh, "Analysis of sampled-data systems," *Trans. AIEE*, vol. 71, pt. 2, pp. 225–232; November, 1952.

[11] E. I. Jury, "Sample-Data Control Systems," John Wiley and Sons, Inc., New York, N. Y.; 1958.

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TABLE I

LAURENT-CAUCHY TRANSFORMS

1) Operational Forms

h_n	$H(\rho)$
$C_1h_n \pm C_2g_n$	$C_1H(\rho) \pm C_2G(\rho)$
$\Delta h_n = h_{n+1} - h_n$	$(\rho-1)H(\rho)$
$\Delta^2 h_n = h_{n+2} - 2h_{n+1} + h_n$	$(\rho-1)^2H(\rho)$
$\Delta^k h_n$	$(\rho-1)^kH(\rho)$
$u_n = \begin{cases} 1; \text{ for } n \geq 0 \\ 0; \text{ otherwise} \end{cases}$	$\frac{\rho}{\rho-1}$
$\delta_n = \begin{cases} 1; \ n = 0 \\ 0: \ n \neq 0 \end{cases}$	1
δ_{n-k}	ρ^{-k}
n	$\frac{\rho}{(\rho-1)^2}$
n^2	$\frac{\rho(\rho+1)}{(\rho-1)^3}$
n^3	$\frac{\rho(\rho^2+4\rho+1)}{(\rho-1)^4}$
n^k	$(-1)^kD^k\left(\frac{\rho}{\rho-1}\right); D = \rho\frac{d}{d\rho}$
$a^{-n}h_n; \quad a > 0$	$H(a\rho)$
$a^n h_n$	$H\left(\frac{\rho}{a}\right)$
h_{n+k}	$\rho^kH(\rho) - \sum_{r=0} h_r\rho^{k-r}$
h_{n-k}	$\rho^{-k}H(\rho)$
$e^{an}h_n$	$H(e^{-a}\rho)$
$\sum_{k=0}^{n} h_kg_{n-k} = \sum_{k=0}^{n} g_kh_{n-k}$	$H(\rho)G(\rho)$
$\sum_{k=0}^{n} kh_kg_{n-k}$	$-H'(\rho)G(\rho)$
$\sum_{k=0} k^ah_kg_{n-k}$	$(-1)^aH^{(a)}(\rho)G(\rho)$
$\sum_{k=0}^{n} g_kg_{n-k}$	$G^2(\rho)$
$h_{n+k} = h_n$	$\frac{\sum_{r=0}^{k} h_r\rho^{k-r}}{\rho^k-1} = \frac{\sum_{r=0}^{k} h_r\rho^{-r}}{1-\rho^{-k}}$
$h_{n+k} = -h_n$	$\frac{\sum_{r=0}^{k} h_r\rho^{-r}}{1-\rho^{-k}}$
$-nh_n$	$\rho H'(\rho)$
$n(n-1)h_{n-1}$	$\rho H''(\rho)$
$-n(n-1)(n-2)h_{n-2}$	$\rho H'''(\rho)$
$(-1)^kn(n-1)'''(n-k+1)h_{n-k+1}$	$\rho H^{(k)}(\rho)$
h_{n+1}	$\rho H(\rho) - h_0\rho$
n^2h_n	$\rho^2H''(\rho) + \rho H'(\rho)$
$\sum_{k=0} h_ku_{n-k}$	$\frac{\rho H(\rho)}{\rho-1}$
$\sum_{k=0} k^2g_kg_{n-k}$	$G''(\rho)G(\rho)$
$\sum_{k=0} kg_kg_{n-k}$	$-G'(\rho)G(\rho)$
$-(n-1)h_{n-1}$	$H'(\rho)$
$(n-1)(n-2)h_{n-2}$	$H''(\rho)$
$-(n-1)(n-2)(n-3)h_{n-3}$	$H'''(\rho)$
$(-1)^k(n-1)\cdots(n-k)h_{n-k}$	$H^{(k)}(\rho)$

2) Functional Forms

h_n	$H(\rho)$
e^{-an}	$\frac{1}{1-e^{-a}\rho^{-1}}$
$1-e^{-an}$	$\frac{\rho^{-1}(1-e^{-a})}{(1-\rho^{-1})(1-e^{-a}\rho^{-1})}$
$\sin an$	$\frac{\rho\sin a}{\rho^2-2\rho\cos a+1}$
$\frac{1}{n!}$	$e^{1/\rho}$
$\cos an$	$\frac{1-\rho^{-1}\cos a}{1-(2\cos a)\rho^{-1}+\rho^{-2}}$
a^{bn}	$\frac{\rho}{\rho-ab}$
ah_n	$aH(\rho)$
h_{nr}	$H(\rho^{-r})$
$\sum_{r=0}^{k} a_r\rho_r^{\,n-1}$	$\frac{(\rho-q_0)\cdots(\rho-q_m)}{(\rho-\rho_0)\cdots(\rho-\rho_k)}$
where: a_r are the residues of the transform	
$-\frac{1}{n}$	$(\rho-1)+\log(\rho-1)$
e	$\frac{\epsilon^\rho}{\rho-1}$
$e^a a^n$	$\frac{e^\rho}{\rho-a}$
$a^n\sin a$	$\frac{\sin\rho}{\rho-a}$
$\frac{a^n\sin a\,(1-(-1)^n)}{\rho a^2}$	$\frac{\sin\rho}{\rho^2-a^2}$
$(\sin a)^{n-1}$	$\frac{1}{\rho-\sin a}$
$(\sin a)^n$	$\frac{\rho}{\rho-\sin a}$
$(\cos a)^{n-1}$	$\frac{1}{\rho-\cos a}$
$(\cos a)^n$	$\frac{\rho}{\rho-\cos a}$
$a^n\log a$	$\frac{\rho\log\rho}{\rho-a}$
$-n^3h_n$	$\rho^3H'''(\rho)+3\rho^2H''(\rho)$
$e^{-\alpha n}\sin an$	$\frac{\rho e^{-\alpha}\sin a}{\rho^2-2e^{-\alpha}\rho\cos a+1}$
$\frac{e^{-an}-e^{-bn}}{e^{-a}-e^{-b}}$	$\frac{\rho}{(\rho-e^{-a})(\rho-e^{-b})}$
$\frac{(-1)^{m-1}}{(m-1)!}\frac{\partial^{m-1}}{\partial a^{m-1}}(e^{-an})$	$\frac{(-1)^{m-1}}{(m-1)!}\frac{\partial^{m-1}}{\partial a^{m-1}}\frac{\rho}{(\rho-e^{-a})}$
$n^{[k]}h_n$	$(-1)^k\rho^k\frac{d^k}{d\rho^k}[H(\rho)]$
where: $n^{[k]} \equiv n(n-1)\cdots(n-k)$	
$\frac{(n+k)!}{(n-1)!}h_{n-k}$	$(-1)^k\rho^{2k}\frac{d^k}{d\rho^k}[H(\rho)]$
$a^{n-1}\log a$	$\frac{\log\rho}{\rho-a}$

TABLE I (Continued)

2) Functional Forms (Continued)

h_n	$H(\rho)$
$\frac{(n-1)(n-2)\cdots(n-k-1)}{(k-1)!}a^{n-k-1}$	$\frac{1}{(\rho-a)^k}$
$\frac{a^n}{a(a-b)}+\frac{b^n}{(b-a)b}$	$\frac{1}{(\rho-a)(\rho-b)}$
$\frac{a^n}{a-b}+\frac{b^n}{b-a}$	$\frac{\rho}{(\rho-a)(\rho-b)}$
$\frac{a^n}{2a^2}+\frac{(-a)^n}{2a^2}$	$\frac{1}{\rho^2-a^2}$
$\frac{a^n}{2a}+\frac{(-a)^n}{2a}$	$\frac{\rho}{\rho^2-a^2}$
$(n+1)h_{n+1}$	$-\rho^2H'(\rho)$
$n(n+1)h_n$	$\rho^2H''(\rho)$
nh_{n+1}	$-\rho H'(\rho)-H(\rho)-h_0$
$\frac{h_{n+2}}{n+1}$	$h_0\rho^2+h_1\rho\log\rho-\rho\int H(\rho)d\rho$
$\frac{h_{n+2}}{n+1};\begin{cases}h_0=0\\h_1=0\end{cases}$	$-\rho\int H(\rho)d\rho$
$\frac{1}{(n+1)!}$	$\rho e^{1/\rho}$

3) Theorems

a) Initial value theorem

$$\lim_{n\to\infty} h_n = \lim_{\rho\to\infty} H(\rho).$$

b) Final value theorem

$$\lim_{n\to 0} h_n = \lim_{\rho\to 1} (\rho-1)H(\rho).$$

c) Unit value theorem

Case I: $H(\rho)$ has no poles in the contour C

$$\sum_{n=0}^{\infty} h_n = \lim_{\rho\to 1} H(\rho).$$

Case II: $H(\rho)$ has poles inside the contour C

$$\sum_{n=0}^{\infty} h_n = \frac{1}{2\pi j}\int_C \frac{H(\rho)}{\rho-1}\,d\rho.$$

d) Summation Theorems

$$\sum_{n=0}^{\infty} f_n = \frac{1}{2\pi j}\int_C \frac{F(\rho)}{\rho(1-\rho)}\,d\rho$$

$$\sum_{n=0}^{k} f_n = \frac{1}{2\pi j}\int_C \frac{F(\rho)(1-\rho^{k+1})}{\rho(1-\rho)}\,d\rho$$

$$\sum_{n=0}^{\infty} y_nh_n = \frac{1}{2\pi j}\int_C \rho^{-1}Y(\rho)H(\rho^{-1})d\rho$$

$$\sum_{n=0}^{\infty} y_n^2 = \frac{1}{2\pi j}\int_C \rho^{-1}Y(\rho)Y(\rho^{-1})d\rho.$$

CORRECTION

J. J. Bussgang, P. Nesbeda, and H. Safran, authors of "A Unified Analysis of Range Performance of CW, Pulse and Pulse Doppler Radar," which appeared on pages 1753–1762 of the October, 1959, issue of PROCEEDINGS, have requested that the following corrections, resulting from an inquiry by M. Skolnik, be made to their paper.

In Case 3, on page 1756, a pulse Doppler radar was compared with a pulse radar of the same average power, antenna gain and noise figure. It was found incorrectly that the former type of radar had a detection range 80 per cent greater than the latter. The error which occurred was due to the fact that the conditions of this Case were not consistent with the earlier text.

Specifically, in the second column on page 1757, the last sentence before the subheading states: "For the pulse radar, N is the actual number of pulses." This is consistent with the earlier statement on page 1756, immediately following (6): "In (6) B_{IF} is assumed to match the pulse width"; *i.e.*, $B_{IF}\tau=1$.

However, our Case 3 is not consistent with this assumption, namely,

$$B_{\text{IF}}\tau = (5\times10^6)(2\times10^{-6}) = 10.$$

Thus each pulse is constituted of 10 independent samples and we should have taken

$$N = (\text{number of pulses})\times(B_{\text{IF}}\tau),$$

or, for Case 3,

$$N = 10\times10 = 100,\ \text{with } N = 100;$$

in Fig. 5, we now read

$$(R/R_0)_p = 1.14. \tag{35'}$$

Hence the over-all result should have been

$$(R)_d/(R)_p = \frac{(R/R_0)_d}{[(R/R_0)_p]\cdot[(R_0)_p/(R_0)_d]} = \frac{0.76}{1.14\times0.55} = 1.21$$

rather than $(R)_d/(R)_p=1.8$.

Thus in this particular Case, the pulse Doppler radar has 21 per cent more detection range.

Apart from noting this error, the authors wish to emphasize that it was not their intent to claim in this example that the pulse Doppler radar is superior in performance to the pulse radar under all circumstances. The purpose of the example was to demonstrate a method of comparison. Were a different set of parameters selected, the conclusions may well have been reversed. In particular, in this example the IF bandwidth was much wider than would be normally required and was quite unfavorable to a pulse radar.

Correspondence

Radio Frequency Scattering from the Surface of the Moon*

Several investigations of the lunar surface, using pulses which are short compared to lunar dimensions, have identified the marked "high-light" returned by quasispecular reflection from the central region of the lunar face.[1–5] Our observations, using a high-power, 400-mc radar show that the moon behaves not only as a smooth reflector but also as a diffuse scatterer. It is the purpose of this communication to show that weak, transient echoes are present from the entire lunar surface that is within view of the earth, provided that sufficient equipment sensitivity is employed.

Two radars, each equipped with a fully-steerable parabolic reflector, have been used in the course of these investigations and are described in Table I.

A typical intensity-modulated, range vs time display of the echoes observed with the more sensitive radar in Scotland is shown in Fig. 1. Transient echoes are detectable out to ranges corresponding to the limbs of the moon. The echoes appear to change range rapidly, a phenomenon which is presumably explainable by interference between energy packets arriving from the moon at the same time but having different Doppler shifts. A better indication of the manner in which received power falls off with distance is shown by the 15-second superposition of *A*-scope pulses shown in Fig. 2. A strong echo from the first 400 kilometers is the most prominent feature, followed by a linear decrease of echo energy[6] with range.

If each element of the lunar surface is assumed to scatter energy isotropically, *i.e.*, $P(\phi)=1$, where $P(\phi)$ = polar diagram of elementary scatterer and ϕ = angle with respect to the direction of specularly-reflected energy, then simple considerations show that the echo power as a function of range should decrease linearly as follows:

$$P_e \propto R\left(1-\frac{x}{R}\right)dx$$

TABLE I

Radar Parameters

	College, Alaska	Fraserburgh, Scotland
Antenna diameter	60 feet	142 feet
Antenna gain	36 db	43 db
Transmitter peak power	50 kw	130 kw
Frequency	398 mc	401 mc
Pulse length	1000 microseconds	300 microseconds
PRF	30 cps	30 cps
Receiver bandwidth	1 kc	6 kc
Polarization transmitted	Linear horizontal	Linear vertical
Received	Horizontal and vertical	Vertical

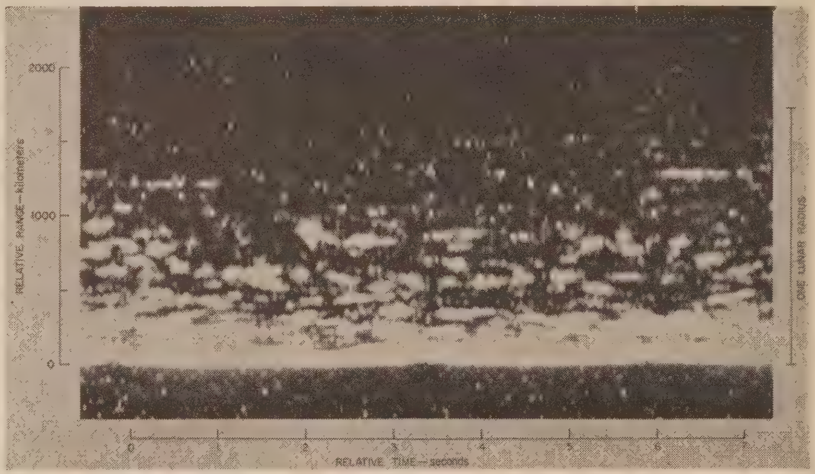

Fig. 1—Intensity-modulated range vs time display of typical lunar echoes observed with Scotland radar. (0550 GMT, December 24, 1959.)

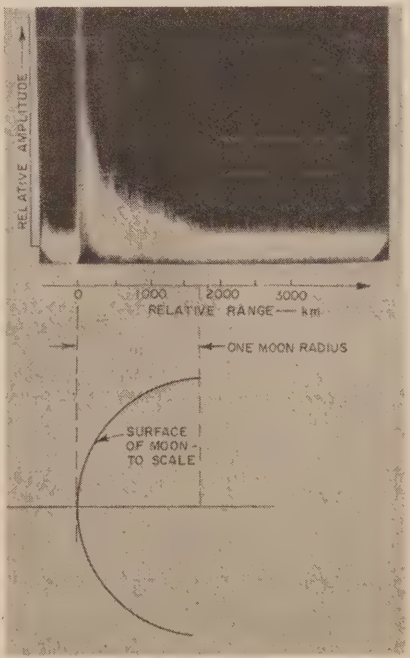

Fig. 2—Amplitude vs range display of lunar echoes with 15 seconds of integration at a pulse repetition frequency of 30 cps.

where

P_e = power reflected,
R = radius of the moon,
x = range measured from front face of the moon,
dx = increment of range.

However, if each element of the lunar surface is assumed to reflect according to a law

$$P(\phi)\propto\left(\frac{\sin\phi}{\phi}\right)^n,$$

then a fit to the initial sharp leading echo might be obtained by selecting an appropriate value for the unknown exponent n.

The echo shown in Fig. 2 shows evidence of both components being present. The two can be separated by fitting a straight line to the tail of the echo and considering the main leading edge to be superimposed on this linear variation. The results of this procedure yield an empirical scattering law of the following form,

$$P(\phi)\propto\left(\frac{\sin\phi}{\phi}\right)^{20\pm 6}+\frac{1}{10}.$$

where $-\pi<\phi<\pi$.

The discovery of this residual echo can be directly attributed to the use of an unusually sensitive radar. In earlier short-pulse experiments, this component was generally immersed in the receiver noise. Its presence is sufficient to explain the observed 20-db discrepancy[2] between the lunar equivalent cross-section values derived by short-pulse, and by continuous wave techniques. In the latter case, the weak component, because of its long time duration, is remarkably effective in contributing to the total echo energy.

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* Received by the IRE, January 22, 1960. This work was supported by Rome Air Dev. Ctr. under Contract AF 30(602)-1871.

[1] B. S. Yaplee, R. H. Bruton, K. J. Craig, and N. G. Roman, "Radar echoes from the moon at a wavelength of 10 cm," Proc. IRE, vol. 46, pp. 293–297; January, 1958.

[2] J. H. Trexler, "Lunar radio echoes," Proc. IRE, vol. 46, pp. 286–292; January, 1958.

[3] T. B. A. Senior and K. M. Siegel, "Radar reflection characteristics of the moon," in *Paris Symposium on Radio Astronomy*," R. N. Bracewell. ed., Stanford University Press, Stanford, Calif., pp. 29–46; 1959.

[4] J. S. Hey and V. A. Hughes, "Radar observations of the moon at 10-cm wavelength," in "Paris Symposium on Radio Astronomy," R. N. Bracewell, ed., Stanford University Press, Stanford, Calif., pp. 13–18; 1959.

[5] A. W. Straiton, and C. W. Tolbert, "Bistatic Moon-Reflection Measurements between Malvern, England and Austin, Texas at 3 KMCS," Electrical Engrg. Res. Lab., University of Texas, Austin, Rept. No. 5-38; November 30, 1959.

[6] The receiver output amplitude shown in Fig. 2 was originally taken to be proportional to input power. Actually, the output is proportional neither to input power nor voltage but to some function between these limits.

The use of short pulses allows the moon to be divided into range increments which appear to the observer as a family of concentric rings (see Fig. 3). On the other hand, a property of a rotating sphere is that loci of constant Doppler shift appear to the observer as linear strips, each parallel to the instantaneous axis of rotation[7] (which can be calculated for the moon). By simultaneously recording both range and Doppler shift (on the order of a few cps at 400 mc), the lunar surface might be mapped with the present equipment without resorting to further resolution in angle.

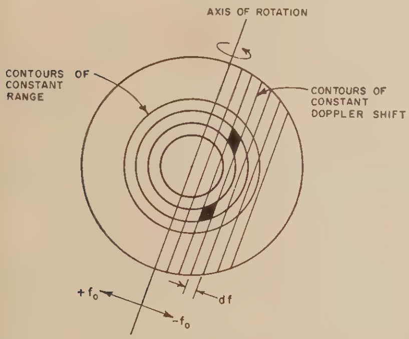
AXIS OF ROTATION
CONTOURS OF CONSTANT RANGE
CONTOURS OF CONSTANT DOPPLER SHIFT
$+f_0$
$-f_0$
df

Fig. 3—Sketch illustrating a scheme for mapping the moon by utilizing range increments and Doppler shift increments. The uncertainty indicated by the blacked areas can be solved by observing the moon at a time when the instantaneous axis of rotation is aligned in a different direction.

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[7] R. Manasse, "The Use of Radar Interferometer Measurements to Study Planets," M.I.T. Lincoln Lab., Cambridge, Mass., Special Rept. 312–23; March 18, 1959.

Measurements of Lunar Reflectivity Using the Millstone Radar*

A new method[1] for mapping the source of radar echoes from distant rotating targets has been applied to lunar echoes obtained by the Millstone Radar of Massachusetts Institute of Technology's Lincoln Laboratory. In this method, an accurate spectral analysis of power density is carried out for each of many range intervals encompassing the extent of the returned signal in frequency and time. For a given apparent target rotation or libration with respect to the radar line of sight there is a proportional relation between the differential frequency displacement of the return and its location along an angular coordinate perpendicular to the instantaneous axis of libration.[2,3] A simultaneous determination of the range will thus fix the return as lying at the intersection of the appropriate range and frequency contour. In the case of a spherical body like the moon, the contours will take the form shown in Fig. 1. Viewed from the side, these contours form a simple rectangular grid bounded by the spherical surface of the moon. The presence of a two-fold ambiguity in the mapping of such data back to the lunar surface should be noted.

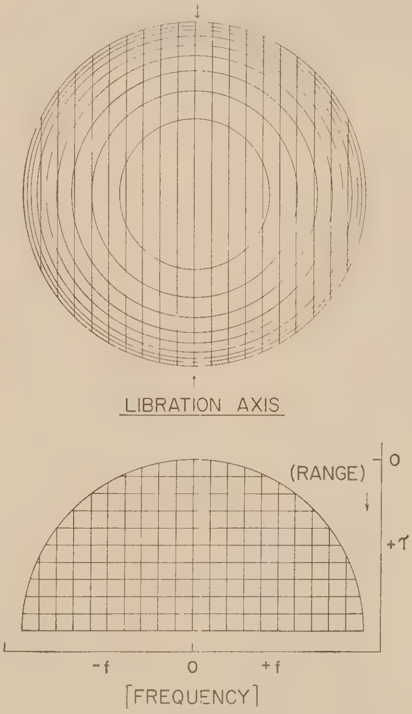

Fig. 1—Range-frequency contours for the moon as viewed from the earth. The Doppler shift arising from motion of the lunar center of mass has been removed.

By the use of a coherent train of short pulses, where the interpulse interval is chosen to be greater than the radar depth of lunar echoes, 11.6 msec, highly accurate frequency data have been obtained at no sacrifice in range resolution. Synthesis of all frequencies used in both transmitter and receiver from a common ultra-stable 1-mc/sec crystal oscillator ensured a maximum of stability. Measurements carried out at a time of exceptionally low lunar libration showed an over-all frequency stability of better than 5 parts in 10^{11} over the echo time of approximately 2.5 seconds. Digital recording of the returned signal waveform, in both amplitude and phase, allowed analysis at a later time with no loss in accuracy.

Fig. 2 shows a typical set of results obtained using the radar parameters listed in Table I. The format employed may be compared directly with Fig. 1. Each horizontal line displays in compressed form a Fourier analysis of the power density at a given range where the factor necessary to reduce the scale to a common maximum value is shown at the left. A scale factor threshold has been used to suppress noise on those traces devoid of echoes. Receiver and sky noise yields an average power of some 1 or 2 units on the scale shown, or some 50 db below the peak returned signal density. Range increments are in multiples of 500 μsec. The frequency resolution which results from the 9-second pulse train used is approximately 0.1 cps, yielding more than 100 elements transverse to the axis at times of maximum libration.

The qualitative features which are immediately obvious are: the presence of substantial echoes out to the limbs, the sharp bounds to the spectra set by the geometrical constraints of the moon's surface, and the concentration of signal near the upper and lower frequency limits at the longer delay. The latter effect is geometrical and results from the tangential intersection of range and frequency contours in those areas. Each run is processed and displayed automatically by the CG 24 digital computer located at the radar site. Since absolute frequency is preserved in the processing, an interesting byproduct of the experiment is the ability to determine the radial component of the lunar motion with a high degree of accuracy. During periods of low libration it appears possible to achieve a precision of approximately 0.02 cps or 2 parts in 10^6 of the observed Doppler frequency. A measurement of this accuracy may have application to geodesy and astronomy.[4]

The instantaneous axis of libration as viewed from moderate latitudes moves through an angle with respect to the selenographic polar axis which may be quite substantial over the course of a day. Therefore, it should be possible to resolve the remaining hemispheric ambiguity in the source of an echo at least for those cases where one hemisphere dominates. Three runs, spaced apart several minutes in time, have been made to study this effect. Preliminary analysis shows relatively little detailed correlation among the three. It is obvious that much patient work lies ahead before detailed correlation with optical photographs may be attempted. Perhaps of more immediate interest is the ability to select returns from areas of the lunar surface which appear to be optically uniform, and from these to build up a scattering law for unperturbed regions which may yield more precise information on the smoothness of the lunar "seas."

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* Received by the IRE, February 8, 1960. The work reported in this paper was performed by M.I.T. Lincoln Lab., Lexington, Mass., with the joint support of the U. S. Army, Navy and Air Force.

[1] P. Green, "Detection Techniques for Interplanetary Radar Observations," presented at URSI, San Diego, Calif.; October, 1959. Also available as M.I.T. Lincoln Lab. Group Rept., Lexington, Mass., No. 34–84; January, 1960.

[2] F. J. Kerr and C. A. Shain, "Moon echoes and transmission through the ionosphere," Proc. IRE, vol. 39, pp. 230–242; March, 1951.

[3] R. Manasse, "The Use of Radar Interferometer Measurements to Study Planets," M.I.T. Lincoln Lab. Group Rept., Lexington, Mass., No. 312–23; March, 1959.

[4] A. B. Thomas, "Certain physical constants and their relation to the Doppler shift in radio echoes from the moon," *Australian J. Science*, vol. 11, pp. 187–191; June, 1949.

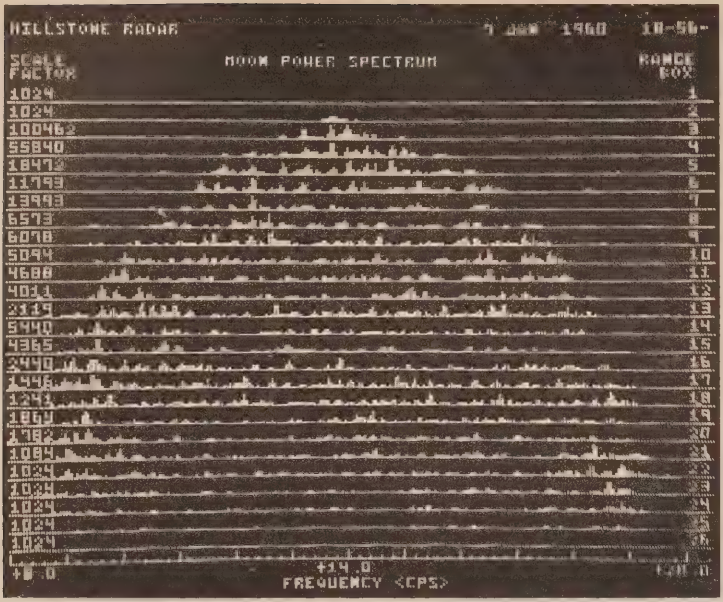

Fig. 2—Processed results of a run made near maximum lunar libration at 1856 EST January 7, 1960 where the range boxes are separated by 500 μsec. Heights are proportional to power.

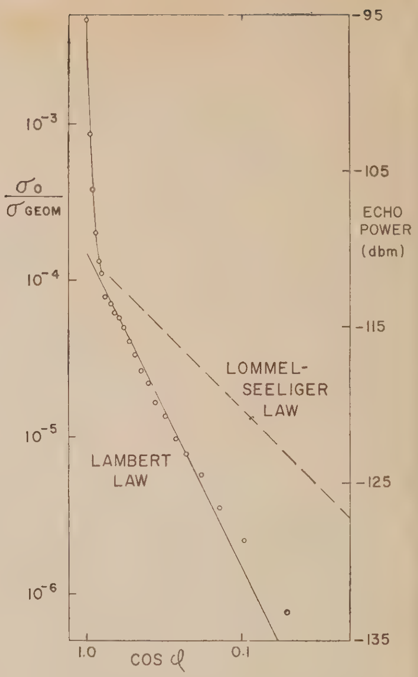

Fig. 3—Distribution of power in moon echoes plotted as a function of the cosine of the angle of incidence to the surface.

TABLE I
RADAR PARAMETERS

Transmitted frequency	440.182 mc
Antenna half-power (one-way) beamwidth	2.1 degrees
Antenna gain (above isotropic radiator)	37 db
Over-all system noise temperature	290°K
Polarization transmitted	right circular
Polarization received	left circular
Peak transmitted power	2.1 megw
Transmitted pulse length	500 μsec
Interpulse period	29.90 msec (exactly)
Pulse repetition rate	33.4448 per second (approx.)
Length of coherent pulse train	8.97 seconds
Sampling interval	500 μsec

As a corollary to the studies above, a measurement of mean total power as a function of range was undertaken. In order to smooth out short term fluctuations, integration was carried out for 16 minutes, including some 24,000 pulses at each 500-μsec range increment. All other parameters were as shown in Table I. Results are plotted in Fig. 3 as received power vs the cosine of the angle of incidence (with respect to the normal) to the lunar surface. Following the decay of the initial specular component, an important amount of diffuse reflection is evident which obeys a Lambert-type law, except for a small amount of limb brightening at extreme ranges. A similar brightening of the extreme limb has been observed optically.[5] The specular and diffuse contributions become equal at a delay of approximately 2 msec from the leading edge of the echo. At the left of the plot is shown the ratio between the radar cross section equivalent to the observed power and the full projected lunar area. For fully specular reflection from a perfectly conducting sphere, this ratio should equal unity at normal incidence and zero elsewhere.[6] Carrying out the integration under the curve yields a ratio between total radar and projected geometric cross section of only 0.01. The discrepancy between this and the higher values obtained by other workers[7] using long pulses or CW is unexplainable and will be a subject of future study. A comparison of the relative amounts of specular and diffuse reflection indicates that an average of about 10 per cent of the lunar surface is sufficiently rough at this frequency to exhibit Lambert scattering.

Without the invaluable aid of J. C. Henry, L. G. Kraft and G. Hyde, it would have been impossible to carry out these experiments in so short a time. Much gratitude is due Dr. P. Green for his suggestions and interest in this work.

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[5] A. V. Markov, "Distribution of intensity on the disk of the moon during full moon," *Astron. J.*, (USSR), vol. 25, pp. 172–179; May–June, 1948.

[6] D. D. Grieg, S. Metzger, and R. Waer, "Considerations of moon relay communication," Proc. IRE, vol. 36, pp. 652–663; May, 1948.

[7] Only some of the more recent work can be noted here. Further references will be found in the bibliographies of the following papers:

a) I. C. Browne, J. V. Evans, J. K. Hargreaves, and W. A. S. Murray, "Radio echoes from the moon," *Proc. Phys. Soc. London*, vol. 69, pp. 901–920; September, 1956.
b) J. H. Trexler, "Lunar radio echoes," Proc. IRE, vol. 46, pp. 286–292; January, 1958.
c) B. S. Yaplee, R. H. Bruton, K. J. Craig, and N. G. Roman, "Radar echoes from the moon at a wavelength of 10 cm," Proc. IRE, vol. 46, pp. 293–297; January, 1958.
d) S. Fricker, *et al.*, "Computation and measurement of fading rate of moon reflected UHF signals," submitted to *J. Geo. Res.*; January, 1960.

Lunar Echoes Received on Spaced Receivers at 106.1 mc*

The primary characteristics of VHF echoes from the moon, such as libration fading,[1,2] Doppler shift,[2] polarization rotation,[3–5]

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* Received by the IRE, February 4, 1960. This work was supported by the Rome Air Development Center, Griffiss AFB, Rome, N. Y., under contract number AF 30(602)-1762.

[1] J. C. Browne, J. V. Evans, J. K. Hargreaves, and W. A. S. Murray, "Radio echoes from the moon," *Proc. Phys. Soc.*, vol. 69, pp. 901–920; September 1956.

[2] S. J. Fricker, P. Ingalls, W. C. Mason, M. L. Stone, and D. W. Swift, "Characteristics of Moon Reflected UHF Signals," M.I.T. Lincoln Lab., Lexington, Mass., Tech. Rept. No. 187; December 22, 1958.

[3] J. V. Evans, "The electron content of the ionosphere," *J. Atmos. Terr. Phys.*, vol. 11, No. 3–4, pp. 259–271; 1957.

[4] F. B. Daniels and S. J. Bauer, "The ionospheric Faraday effect and its application," *J. Franklin Inst.*, vol. 267, pp. 187–200; 1959.

[5] R. A. Hill and R. B. Dyce, "Some observations of ionospheric Faraday rotation on 106.1 mc," *J. Geophys. Res.*, vol. 65, pp. 173–176; January, 1960.

TABLE I

Summary of Equipment Parameters

	Radar	Bus	Truck
Transmitter power	50 kw, peak	—	·
Antenna	60-foot diameter parabolic dish	Square array of 16 four-element Yagis	Square array of 16 four-element Yagis
Antenna beamwidth	12°	15°	15°
Received polarization	Horizontal and vertical	Vertical	Vertical
Receiver bandwidth	Approx. 200 cps	Approx. 200 cps	Approx. 200 cps
Location (first test) (second test)	37.4°N, 122.2°W same as above	5.7 km, west 1.8 km, north	2.9 km, north same as above

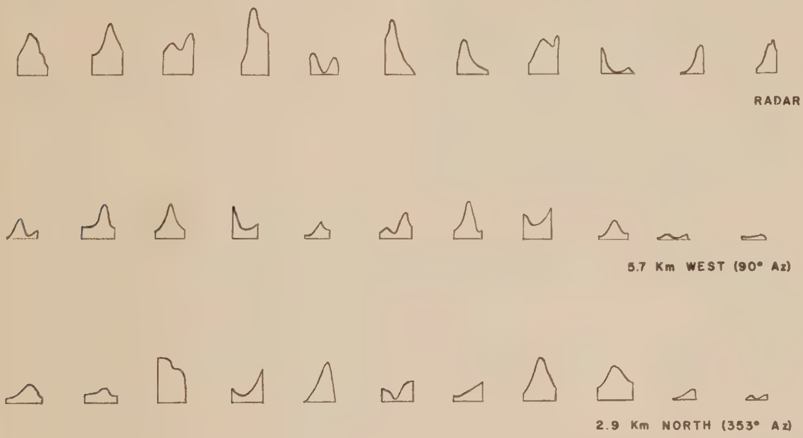

Fig. 1—Echoes from the moon on 106.1 mc, showing uncorrelated fluctuations at separated receivers, on January 11, 1958, at 0500–0501 PST, when the moon was near upper culmination. (Azimuth, 177°; elevation, 47°.)

absolute range,[6] and pulse broadening,[7–9] have been described by previous authors. This communication describes an attempt to measure the size of the patches of energy reflected onto the earth's surface and their possible velocities of motion along the earth's surface.

The moon, located in the broad beam of the transmitter, can be regarded as an irregularly-illuminated aperture having an irregular phase distribution. Thus, the moon may behave as an antenna having a complicated radiation pattern but having a narrowest lobe size given by the effective "width" of the lunar aperture. Thus, the minimum size of each of these patches is dependent upon the maximum subtended angle of the effective reflecting portion of the lunar surface.

In conjunction with the 106.1-mc radar employed by Stanford Research Institute for lunar echo studies, two partially mobile antennas, receivers, and recorders were assembled for use as remote receiving stations. (See Table I.) The antennas were directed at the moon approximately every 15 minutes using precomputed values of azimuth and elevation. Each of the three sites was equipped with a frequency-converter, Collins 51J4 receiver (bandwidth of approximately 200 cps) and a pen-chart (Brush) recorder capable of following the fastest variations of the libration-caused lunar echo fading. The transmitter was turned on (CW) for about 2.4 seconds and repeated every 5.1 seconds. With this timing, the echo from the moon began to return shortly after the transmitter pulse had ended, giving a useful received signal 40 per cent of the total period

Typical results from the first test are shown in Fig. 1. Correlation between these traces is less than 0.02. In April, 1958, the bus was moved to a convenient location approximately bisecting the line between the truck and the radar. Again, the results were largely uncorrelated. For the closest spacing used (1.15 kilometers north-south or 0.8 km projected) and after compensating for gain changes during the runs, the best correlation that could be achieved was 0.26. A search was made for similar amplitude fluctuation patterns shifted in time, in hopes of establishing a westward drift because of the earth's eastward motion. No pattern drift was found, possibly because the transmitter is not fixed with respect to the moon.

This result implies that much, if not all, of the lunar surface is effective in echoing a man-made signal. More definitive results would result, of course, using short-pulse experiments. For communication via the moon, this result implies that a diversity distance of about one kilometer projected at right angles to the radio ray is certainly sufficient spacing to achieve diversity reception.

The research was made possible through the initiative of R. L. Leadabrand and through the willing efforts and long hours of more than a dozen assistants within the laboratory.

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[6] B. S. Yaplee, R. H. Bruton, K. J. Craig, and N. G. Roman, "Radar echoes from the moon at a wavelength of 10 cm," Proc. IRE, vol. 46, pp. 293–297; January, 1958.

[7] J. H. Trexler, "Lunar radio echoes," Proc. IRE, vol. 46, pp. 286–292; January, 1958.

[8] J. S. Hey and V. A. Hughes, "Radar observations of the moon at 10-cm wavelength," in "Paris Symposium on Radio Astronomy," R. N. Bracewell, ed., Stanford University Press, Stanford, Calif.; 1959.

[9] R. L. Leadabrand, R. B. Dyce, A. Fredriksen, R. I. Presnell, and J. C. Schlobohm, "Radio frequency scattering from the surface of the moon," Pp. 932–933, this issue.

Noise Figure of Tunnel Diode Mixer*

An analysis has been made of the noise figure of a tunnel diode used as a mixer. The assumptions made were 1) the diode sees a short circuit at the image frequency, 2) the only source of noise in the diode is the shot noise associated with the tunnel current, 3) the series resistance of the diode and the losses of the input and output tuned circuits are negligible, and 4) the diode capacitance is constant. Because of the second assumption, consideration is limited to that portion of the i–v characteristic of the diode extending from reverse voltages up to, or somewhat beyond, the point of maximum negative conductance. In particular, the valley of the i–v characteristic is excluded from consideration because considerable excess $1/f$-type noise[1] has been observed in this region and this type of noise is not taken into account in the analysis.

Since the conductance of a tunnel diode can assume negative values, the possibility of a conversion gain greater than unity may be anticipated. The midband conversion power gain of a nonlinear resistance type of diode, defined as the ratio of IF output power to the power available from the RF source is

$$G = \frac{4r_1r_2g_1^2}{[(1+g_0r_1)(1+g_0r_2) - g_1^2r_1r_2]^2}. \quad (1)$$

In (1), r_1 and r_2 are the resistances seen by the diode at RF and IF, respectively, g_0 is the average conductance of the diode over the local oscillator cycle, and g_1 is the conversion conductance of the diode. The values of g_0 and g_1 are obtained from the Fourier series representation of the instantaneous incremental conductance g of the diode considered as a function of the local oscillator phase θ. Thus

$$g(\theta) = g_0 + 2g_1 \cos\theta + 2g_2 \cos 2\theta + \cdots. \quad (2)$$

If $g(\theta)$ is restricted to non-negative values then $0 \leq |g_1| \leq g_0$ and the maximum possible value of G for positive r_1 and r_2 is unity.

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* Received by the IRE, January 22, 1960.

[1] T. Yajima and L. Esaki, "Excess noise in narrow germanium *p-n* junctions," *J. Phys. Soc. Japan*, vol. 13, pp. 1281–1287; November, 1958.

However, if $g(\theta)$ is free to assume negative values, then $g_0 < |g_1|$ is possible and the conversion gain cannot only exceed unity, but will become infinite for

$$r_2 = r_{2c} = \frac{1 + g_0 r_1}{g_1^2 r_1 - g_0(1 + g_0 r_1)}. \tag{3}$$

It can be shown that for stable operation the quantities $(1+g_0r_1)$ and $(1+g_0r_2)$ must both be positive or both negative. Assuming that both are positive, the condition that r_{2c} be positive is that

$$\gamma = \frac{|g_1| r_1}{1 + g_0 r_1} > \frac{g_0}{|g_1|} = \alpha. \tag{4}$$

For values of r_2 slightly below r_{2c}, the mixer gain is similar to that of a negative resistance amplifier; *i.e.*, the product of voltage gain and bandwidth is constant.

The noise figure of the tunnel diode mixer is

$$F = 1 + \frac{q(I_{0f} + I_{0r})}{2kT_1|g_1|} \frac{1 + \gamma^2 \pm 2K\gamma}{\gamma(1 - \alpha\gamma)} + \frac{1}{\gamma(1 - \alpha\gamma)} \frac{1}{|g_1| r_2} \frac{T_2}{T_1}. \tag{5}$$

$$\gamma_{\text{opt}} = \frac{\Big\} \alpha^2 \left(1 - \frac{\alpha}{M}\right)^2 + \left(1 - \frac{\alpha}{M}\right)\left[1 - \alpha\left(2K - \frac{1}{M}\right)\right]\Big\{^{1/2} - \alpha\left(1 - \frac{\alpha}{M}\right)}{1 - \alpha\left(2K - \frac{1}{M}\right)} \tag{9}$$

In (5)

$$K = -\frac{I_{1f} + I_{1r}}{I_{0f} + I_{0r}},$$

T_1 and T_2 are the temperatures of r_1 and r_2, respectively, q is the electronic charge, k is Boltzmann's constant, and the ± sign is to be taken as positive or negative according as g_1 is positive or negative. The quantities I_{0f} and I_{1f} denote the dc and fundamental components of the forward component of the tunnel current as defined by the Fourier series

$$i_f(\theta) = I_{0f} + 2I_{1f}\cos\theta + 2I_{2f}\cos 2\theta + \cdots. \tag{6}$$

Similarly I_{0r} and I_{1r} are the dc and fundamental components of the reverse component i_r of the tunnel current. The net tunnel current that is measurable is $i = i_f - i_r$. To separate i into i_f and i_r, the relations,

$$i_f = \frac{i}{1 - \exp(-qv/kT)},$$
$$i_r = i_f \exp(-qv/kT), \tag{7}$$

may be used. These relations can be derived from the theoretical expression for the tunnel current given in Esaki.[2] In (5) the first term represents thermal noise associated with the resistor r_1, the second term represents shot noise of the diode and the third term the thermal noise associated with r_2.

The derivation of (5) is similar to the derivation of the noise figure of a diode mixer given in Strutt,[3] except that the mean square shot noise at any point in the local oscillator cycle is set equal to $2q(i_r + i_f)\Delta f$ instead of $4kT_c g\Delta f$ as in (5) of Strutt.[3]

According to (5) of this note, the larger r_2 the better the noise figure of the mixer. However, the mixer conversion gain is more critically dependent on r_2 and high conversion gain is desirable to minimize the over-all noise figure of the system. In the absence of specific informarion concerning the noise figure of the IF amplifier, it appears reasonable to choose

$$r_2 \cong r_{2c} = \frac{1}{|g_1|(\gamma - \alpha)}. \tag{8}$$

For this choise of r_2, F has a minimum for $\gamma = \gamma_{\text{opt}}$ where

and

$$M = \frac{q(I_{0f} + I_{0r})}{2kT_2|g_1|}. \tag{10}$$

The above results were used to calculate the noise figure as a mixer of a G.E. ZJ56 germanium tunnel diode. The calculation was made for various values of bias and local oscillator drive on the assumption that the local oscillator voltage across the diode is sinusoidal. The best value obtained for the noise figure was 8.3 db for a forward bias of 100 mv and a peak local oscillator voltage of 90 mv. For this set of operating conditions $g_0 = +0.0029$ mho, $g_1 = -0.0069$ mho, $I_0 = 0.924$ ma, $I_1 = -0.346$ ma, $r_{1\,\text{opt}} = 135$ ohms and $r_{2c} = 600$ ohms. By way of comparison, the same diode used as a negative-resistance amplifier has a noise figure of about 5 db. The noise figure as a mixer is thus poorer than the noise figure as an amplifier. This result is to be expected unless more effective use can be made of "noise compensation" in the mixer.[4] Unfortunately, to obtain significant noise compensation, Class C operation of the diode is required and this mode of operation is not possible for the tunnel diode.

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[2] L. Esaki, "New phenomenon in narrow Ge *p-n* junctions," *Phys. Rev.*, vol. 109, pp. 603–604; January, 1958.

[3] M. J. O. Strutt, "Noise figure reduction in mixer stages," Proc. IRE, vol. 34, pp. 942–950; December, 1946.

[4] A. van der Ziel, "Noise," Prentice-Hall, Inc., New York, N. Y., pp. 249–250; 1954.

Effect of External Base and Emitter Resistors on Noise Figure*

Neilsen[1] has shown that the noise figure of a transistor in the common-emitter configuration is

$$F = 1 + \frac{r_b' + \frac{r_e}{2}}{R_g} + \frac{(1 - \alpha_0)\left[1 + \left(\frac{f}{\sqrt{1 - \alpha_0} f_\alpha}\right)^2\right](r_b' + r_e + R_g)^2}{2\alpha_0 r_e R_g}, \tag{1}$$

where R_g is the source resistance. The value of R_g for which F is minimum is

$$R_{gm} = \sqrt{\frac{2\alpha_0 r_e\left(r_b' + \frac{r_e}{2}\right)}{(1-\alpha_0)\left[1 + \left(\frac{f}{\sqrt{1 - \alpha_0} f_\alpha}\right)^2\right]} \cdots + (r_b' + r_e)^2}. \tag{2}$$

These expressions neglect both excess $(1/f)$ noise in the transistor and the noise contribution of any external elements such as bias resistors.

Middlebrook[2] has derived expressions for the noise figure and optimum source resistance of a common-emitter transistor amplifier containing external base and emitter resistors, but these expressions do not account for the effect of the transistor input resistance.

It is possible to derive expressions for the noise figure and optimum source resistance of an amplifier which neglect only excess noise in the transistor. Fig. 1 shows an approximate equivalent circuit of a common-emitter amplifier. R_1 is a base biasing resistor and R_2 is an unbypassed emitter resistor. The noise figure of this circuit is

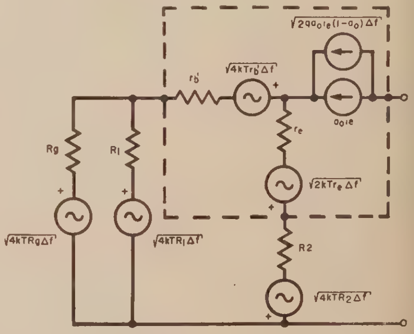

Fig. 1—Equivalent circuit of a common-emitter amplifier containing noise sources.

$$F' = 1 + \frac{R_g}{R_1} + \left(1 + \frac{R_g}{R_1}\right)^2 \left[\frac{r_b' + \frac{r_e}{2} + R_2}{R_g} + \frac{(1 - \alpha_0)(r_{b'} + r_e + R_2 + R_p)^2}{2\alpha_0 re R_g}\right], \tag{3}$$

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* Received by the IRE, January 4, 1960.

[1] E. G. Neilsen, "Behavior of noise figure in junction transistors," Proc. IRE, vol. 45, pp. 957–963; July, 1957.

[2] R. D. Middlebrook, "Optimum noise performance of transistor input circuits," *Semiconductor Products*, vol. 1, pp. 14–20; July/August, 1958.

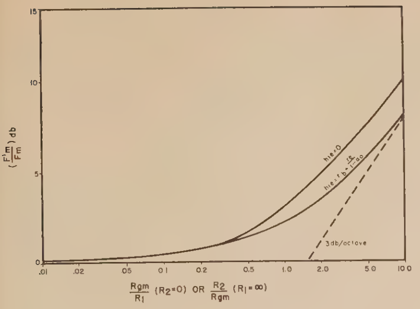

Fig. 2—Increase in minimum noise figure caused by R_1 or R_2.

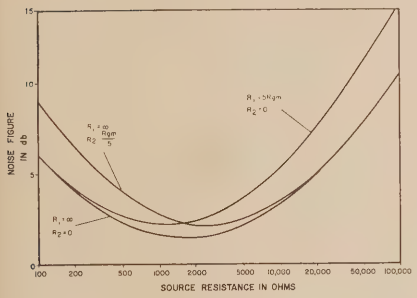

Fig. 3—Variation of noise figure vs source resistance with R_1 and R_2 as parameters.

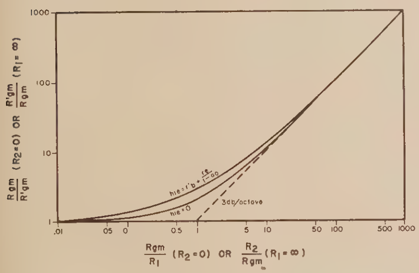

Fig. 4—Optimum source resistance R_{gm}' as a function of R_1 or R_2.

where R_p is $(R_1R_g)/(R_1+R_g)$. In (3), it is assumed that $f \ll \sqrt{1-\alpha_0}\, f\alpha$.

The amplifier noise figure (F') has a minimum value for $R_g = R_{gm}'$, where R_{gm}' is related to R_{gm} by

$$\frac{R_{gm}}{R_{gm}'} = \left[\frac{1+\dfrac{R_{gm}^2+R_2(2h_{ie}+R_2)}{R_1^2}+\dfrac{2(h_{ie}+R_2)}{R_1}}{1+\left(\dfrac{R_2}{R_{gm}}\right)^2+\dfrac{2h_{ie}R_2}{R_{gm}^2}}\right]^{1/2}. \quad (4)$$

In (4), $h_{ie} = r_b' + r_e/(1-\alpha_0)$ and is the low-frequency, common-emitter input resistance of the transistor.

Eq. (3) shows that the presence of R_1 and R_2 increases the amplifier noise figure. In Fig. 2, the ratio of the minimum amplifier noise figure to the minimum transistor noise figure, in db, is plotted vs R_{gm}/R_1 and R_2/R_{gm}, for a typical transistor having the following parameters:

$$r_e = 50 \text{ ohms}$$
$$r_b' = 250 \text{ ohms}$$
$$\alpha_0 = 0.990.$$

The ratio F_m'/F_m, in db, approaches an asymptote of 3 db per octave. Note that the effect of the input resistance is to shift the "break point" of the curve from a normalized value of unity to some greater value. The input resistance, therefore, reduces the degradation of the noise figure caused by R_1 and R_2.

Fig. 3 shows the variation of amplifier noise figure vs source resistance for typical values of R_1 and R_2. In accord with (4), it is seen that a finite value of R_1 decreases the value of the optimum source resistance, while a nonzero value of R_2 increases the optimum source resistance. Fig. 4 shows the behavior of the optimum source resistance with variation in R_1 and R_2. At low values of R_1, R_{gm}' approaches R_1, while at high values of R_2, R_{gm}' approaches R_2. The input resistance accentuates the effect of a given R_1 or R_2 on the optimum source resistance.

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A Ferromagnetic Amplifier Using Longitudinal Pumping*

A number of ferromagnetic parametric amplifiers using a transverse RF magnetic field as the pump have been proposed and investigated.[1–4] However, for various reasons none of these amplifiers has resulted in a practical device. It now appears that a ferromagnetic amplifier can be built using longitudinal pumping (RF magnetic field parallel to the dc magnetic field). Early experimental results on this type of amplifier have given a CW gain of 25 db with a signal frequency in the 4000-mc range using an X-band pump power of less than a watt.

The amplifier consists of a sample of ferromagnetic material mounted in a cavity, resonant at the pump frequency, with a transmission line to couple energy into the sample at the signal frequency. Resonances at the signal and idler frequencies are provided by normal modes of the ferromagnetic material.[5] The normal modes of a spheroidal sample of ferromagnetic material have been obtained by Walker,[6] and a straightforward calculation shows that certain pairs of these modes can be pumped parametrically by an RF field in the longitudinal direction. The calculation indicates which pairs of modes can be pumped and their respective thresholds for oscillation. The restriction on the pairs of modes which can be pumped comes from the form of the magnetostatic potentials as obtained by Walker and can be expressed as a set of selection rules. The magnetic field must, of course, be adjusted so that the resonant frequencies of the modes add up to the pumping frequency.

The ferromagnetic sample was a sphere of single-crystal yttrium iron garnet 0.043 inches in diameter mounted in a half-wave X-band cavity at a point of maximum RF magnetic field and spaced 0.075 inches from the cavity wall. The sphere, which had a linewidth of 0.40 oersteds, was furnished by Spencer and LeCraw. A loop of wire was threaded through holes in the wall of the cavity and around the sphere in a plane containing the dc and RF magnetic fields, to provide coupling from a coaxial line into the sample. A measure of the strength of coupling between the loop and the sample modes was obtained by observing the reflection of a signal in the coaxial line in the absence of the pump: 64 resonances were readily resolved as the dc magnetic field was varied. CW pump excitation of the cavity at 9196 mc was then applied at a power level of 500 mw. At each of a number of dc field values, a pair of modes was observed to undergo steady oscillation. Amplification was obtained by setting the dc field to single out one such pair and by reducing the pump power. Amplifier operation for a typical pair of modes is illustrated in Fig. 1, which shows reflection by the sphere of a swept frequency signal in the coaxial line without pumping [Fig. 1(a)] and with pumping [Fig. 1(b)]. Note that a number of absorptions due to sample modes appear in Fig. 1(a); the notch in the center is due to a wavemeter at 4598 mc (half the pumping frequency). The modes at 4626 and 4570

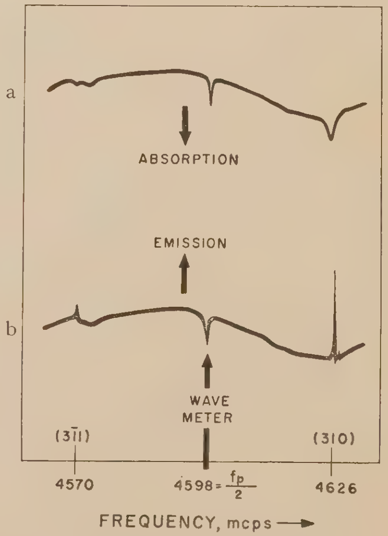

Fig. 1—Walker mode resonances in a YIG sphere. (a) Without pumping. (b) With pumping.

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* Received by the IRE, March 7, 1960.

[1] H. Suhl, "Theory of the ferromagnetic microwave amplifier," *J. Appl. Phys.*, vol. 28, pp. 1225–1236; November, 1957.

[2] M. T. Weiss, "A solid-state microwave amplifier and oscillator using ferrites," *Phys. Rev.*, vol. 107, p. 317; July, 1957.

[3] A. D. Berk, L. Kleinman, and C. E. Nelson, "Modified semistatic ferrite amplifier," 1958 WESCON Convention Record, pt. 3, pp. 9–12.

[4] E. G. Spencer and R. C. LeCraw, "Magnetoacoustic resonance in yttrium iron garnet," *Phys. Rev. Lett.*, vol. 1, pp. 241–243; October, 1958.

[5] This type of operation is similar to that reported by Spencer and LeCraw[4] except that the modes referred to here are magnetic, whereas there they were acoustic vibrations.

[6] L. R. Walker, "Magnetostatic modes in ferromagnetic resonance," *Phys. Rev.*, vol. 105, pp. 390–399; January, 1957.

mc have been identified as the 310 mode and the $3\bar{1}1$ mode (Walker's notation).[6] It may be observed that they satisfy the frequency relation for parametric pumping. They also satisfy the selection rules referred to above. These are the modes which are amplifying in Fig. 1(b). Fig. 2 also shows the energy reflected from the sphere, but on an expanded frequency scale centered about the 310 mode. The gain measurement was performed using a signal generator, the amplifier, and a detector on the arms of a three-port circulator. The detector output was compared with that obtained when a shorting plate was substituted in the amplifier arm, showing a gain of 25 db. Work is still in a very early experimental stage; measurement of bandwidth, noise figure, and other characteristics is proceeding.

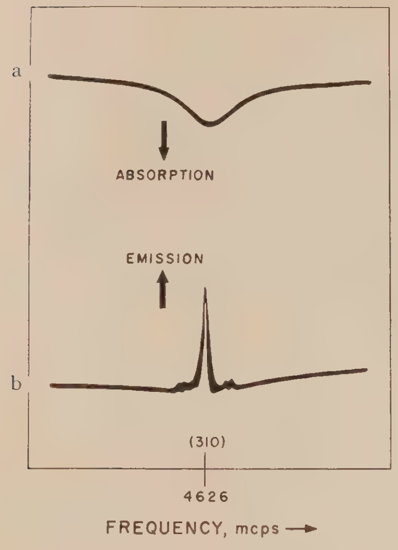

Fig. 2—Walker mode resonance (310) on an expanded scale. (a) Without pumping. (b) With pumping.

This amplifier appears capable of fulfilling the expectations which have made the ferromagnetic parametric amplifier principle attractive: namely, it operates at room temperature but being a magnetic device can also, of course, be operated at low temperatures; it is not susceptible to burnout or long-term saturation caused by high-power transients; and it is capable of being used up to very high signal frequencies. In the style of operation reported here, use at high frequencies ought to present no special difficulties; this amplifier also exhibits the advantages of low pump power and lower dc magnetic field than required in some other proposals.

The investigation of longitudinal pumping which led to this new type of amplifier was stimulated by the work of Schlömann, *et al.*,[7] on the theory of spin-wave excitation, and the studies of LeCraw and Spencer.[8] Spencer and LeCraw have been very generous in devoting time to discussions, offering suggestions, and providing experimental assistance. The author would like to thank J. A. Weiss for many helpful and stimulating discussions. V. Czarniewski has contributed very skillful technical assistance.

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[7] E. Schlömann, J. J. Green, and U. Milano, "Recent Developments in Ferromagnetic Resonance at High Power Levels," presented at Conf. on Magnetism and Magnetic Materials, Detroit, Mich.; November, 1959.

[8] R. C. LeCraw and E. G. Spencer, "Spin-Lattice Relaxation of Low *k*-Number Spin Waves in Yttrium Iron Garnet: I Frequency Dependence," and "Spin-Lattice Relaxation of Low *k*-Number Spin Waves in Yttrium Iron Garnet: II Temperature Dependence," to be presented at the 1960 Meeting of the American Physical Society, Washington, D. C.; 1960.

Parametric Phase Distortionless *L*-Band Limiter*

A. E. Siegman[1] has predicted, from theoretical considerations, that a parametric device could be made to limit at *pump* frequency, without phase distortion. Such a limiter, operating at *L*-band, has successfully been developed in our laboratory. Over 30 db of dynamic limiting has been observed at 1000 mc, with the parametric limiter operating in the degenerate mode. Phase distortion measurements have been made over a 16-db range of limiting. The phase distortion was observed to be less than ±2°, which was the accuracy of the measurements.

Fig. 1 is a schematic of the limiter. Three shorted coaxial transmission line cavities (pump and two idlers) are joined at a tee. A Microwave Associates MA460A VARACTOR is placed in shunt with all three cavities at their junction. Provisions are made for biasing the VARACTOR over the range ±4 volts, with suitable RF bypassing. Two loops couple pump signal in and limited pump signal out of the pump arm. Additional loops are provided in the idler arms for monitoring idler frequencies.

Siegman did not describe an actual device; however, he did suggest, in an example, that the pump cavity be designed to resonate in two degenerate modes at pump frequency. Coupling between modes would be afforded by the nonlinear element. Pump signal would be coupled into one mode, while output signal would be coupled to the second. Limiting occurs when the device breaks into oscillation, causing the nonlinear coupling between the two degenerate modes to "clamp." It appears, from our experience, that such coupled degenerate modes are not a necessary feature for the device to function. In our device, the dimensions of the coaxial pump cavity are such that all higher TE and TM modes are well below cutoff. Both input and output loops couple to the TEM mode, for which no degeneracy exists.

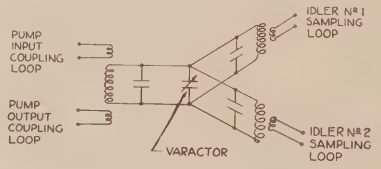

Fig. 1—Schematic of limiter.

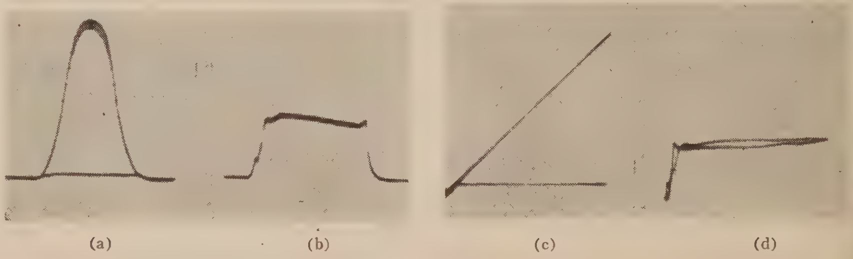

Fig. 2—Oscilloscope photographs of pulsed limiter action. (a) Pseudo-Gaussian input pulse and limited output pulse (dual trace). (b) Expanded output pulse. (c) *X-Y* presentation, input vs input (45° line) and output vs input. (d) Expanded *X-Y* presentation, output vs input.

Tests of the dynamic limiting capabilities were made at 1000 mc, using $3\frac{1}{2}$-μsec (half amplitude width) pseudo-Gaussian RF pulses. Photographs taken using a high-speed *X-Y* oscilloscope are shown in Fig. 2. In Fig. 2(a), a dual trace is shown of the pseudo-Gaussian input pulse and of the limited output pulse. The output pulse is shown again in Fig. 2(b), amplified to show greater detail. Fig. 2(c) is an *X-Y* presentation showing output vs input. The 45° trace is a plot of input vs input, provided for comparison. Fig. 2(d) is again an *X-Y* presentation of output vs input; the output signal has been amplified to show greater detail of the limiting action. The limiter was operat-

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* Received by the IRE, December 28, 1959.

[1] A. E. Siegman, "Phase distortionless limiting by a parametric method," PROC. IRE, vol. 47, pp. 447–448; March, 1959.

ing in the degenerate mode (both idler frequencies at one-half pump frequency). Average input power was 280 mw. Peak input power was in excess of 15 watts.

Phase distortion measurements were conducted under pulsed conditions at 1000 mc, with the limiter operating in the degenerate mode. It is essential, in such measurements, that the phase of the input signal to the limiter does not vary as its amplitude is varied. In other words, the device used to vary input signal amplitude must not in itself introduce phase distortion. Several variable attenuators were found to be lacking in this respect. The problem was solved in the manner illustrated in Fig. 3.

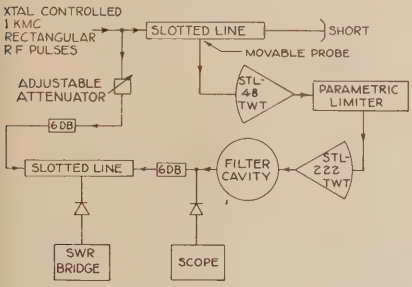

Fig. 3—Experimental setup for phase distortion measurement.

A crystal-controlled source of rectangular pulses at 1000 mc was fed into a shorted slotted line, creating an infinite VSWR on that line. A well-known property of such a standing-wave pattern is that the phase of the RF voltage between adjacent minima is independent of distance along the line. Thus, by moving a probe back and forth between a minimum and a maximum of such a standing-wave pattern, the RF output from the probe could be made to vary over a wide range, the phase remaining constant. It is necessary that the probe be only lightly coupled to the slotted line; otherwise the perturbation of fields introduced by the probe will destroy the above relationship. Therefore, the insertion loss of this amplitude varying device is necessarily high.

The high insertion loss was overcome by amplifying the signal out of the probe to a sufficient level to drive the limiter. A Sperry STL-48 TWT was used for this purpose. This is a high-power (200-watt CW) TWT, chosen so that the power levels at which our phase measurements were to be made were well down in the small signal region, to avoid amplitude-to-phase conversion introduced by the TWT itself. A separate check of this phase distortion due to the TWT was made; over the amplitude range used, it was less than ±2°, which was the accuracy of our measurement.

The limited output was amplified using a Sperry STL-222 TWT, passed through a cavity filter tuned to pump frequency, then through 6 db of lossy cable to one end of a slotted line. A sample of the crystal-controlled RF drive was fed through 6 db of lossy cable to the other end of the slotted line, as phase reference signal. By adjustment of the amplitude of the phase reference signal, an infinite VSWR was established on that slotted line. Any phase shift in the limited output signal caused a corresponding shift in the position of the minimum of standing-wave pattern, which could be correlated directly to phase shift in degrees. Over a 16-db range of limiting, the phase shift was observed to be less than ±2°, the accuracy of our measurement.

It will be noted that the block diagram of Fig. 3 includes a filter cavity, tuned to pump frequency, in the output line of the limiter. Its purpose was to filter out any idler frequencies which might be coupled to the output loop. We found that the limiter worked better when this filter was present. It will also be noted that this filter is isolated from the limiter by a nonreciprocal circuit element (the STL-222 TWT). Thus, the limiter saw an impedance of 50 ohms. We found that this order of component placement worked best. When the filter cavity and the TWT were reversed in position, some "ringing" occurred on the output pulse. This ringing was affected by filter cavity tuning.

The operation of the limiter was observed to be critically dependent upon the tuning adjustment of all three cavities, as well as upon the bias adjustment. There appeared to be a broad combination of idler frequencies F_1 and F_2 satisfying the relationship

$$F_1 + F_2 = F_p$$

such that limiting would occur. However, it was found that the best limiting action occurred when the limiter operated in the degenerate mode, where

$$F_1 = F_2 = F_p/2.$$

The authors wish to express their appreciation to J. R. Ashley, who suggested the experimental technique used for monitoring phase distortion.

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The Diode-Loaded Helix as a Microwave Amplifier*

Earlier work on traveling-wave parametric structures has included cavity devices and transmission line devices.[1] Theoretical and some experimental work has been done at these Laboratories with a diode-loaded coaxial line.[2]

More recently, exploratory work was done with an *S*-band helix-loaded with *p-n* junction diodes, in an attempt to develop a four-terminal microwave amplifier with broad-band properties. In addition to broad-band behavior, the helix structure is directional and the signal and pump sources can be isolated by the helix. It is fairly easy to couple to the helix and this can be done at any point along it if, for instance, distributed pump coupling is desired. *A priori*, a large variation in amount and kind of loading is possible. Experience with the loaded coaxial line has indicated that a small loading per unit length, distributed over the structure, is desirable.

The helix is shown in Fig. 1. It is of silver-plated tungsten wire (20-mils diameter). Designed for *S*-band operation, it is 6 inches long, has a 0.276-inch mean diameter, and has approximately 13 turns per inch. The diodes,[3] mounted between turns of the coil, are of germanium, alloyed-diffused, and have the following characteristics:

Capacitance (−1 volt)	0.2–1 μμf,
Series resistance	2–15 ohms,
Cutoff frequency (nominal)	20–100 kmc.

They were assembled in ceramic cylinders about 0.1 inch in diameter, of axial dimension quite close to that of the interturn spacing of the helix.

The test apparatus is shown schematically in Fig. 2. It was found that the position of each diode on the helix was critical, as was the pump power and pump frequency. No general relations among pump frequency,

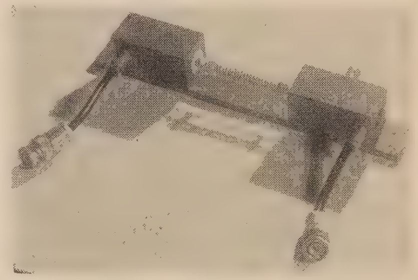

Fig. 1—The helix.

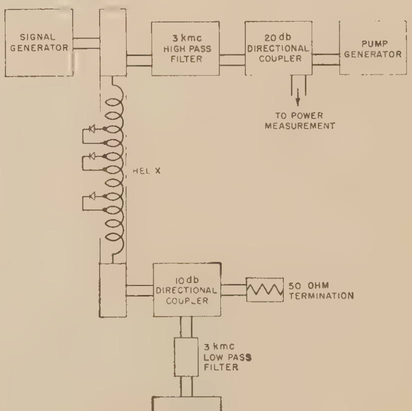

Fig. 2—Schematic of test set-up.

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* Received by the IRE, January 26, 1960. This work was sponsored in part by the Electronics Res. Directorate of the AF Cambridge Res. Center, Air Research and Development Command, under Contract No. AF 19(604)-4980.

[1] P. K. Tien, "Parametric amplification and frequency mixing in propagating circuits," *J. Appl. Phys.*, vol. 29, pp. 1347–1357; September, 1958.

[2] G. Heilmeier, "An analysis of parametric amplification in periodically loaded transmission lines," *RCA Rev.*, vol. 20, pp. 442–454, September, 1959; also, "Research and Development on Parametric Amplifiers," AF Cambridge Res. Ctr., Cambridge, Mass., 2nd Quart. Rept., Contract AF19(604)-4980, June 30, 1959.

[3] Thanks are due C. W. Mueller's Device Group, in these Laboratories, for a supply of developmental diodes.

signal frequency and diode position and characteristics were observed.

Typical operating data are shown in Table I.

TABLE I

Signal frequency	2800 mc
Pump frequency	3800 mc
Number of diodes	2
Pump power	60 mw
Unloaded helix insertion loss	−6 db
Net power gain	26 db
Voltage gain-bandwidth	30 mc
Noise figure	5–7 db

It can be seen that the bandwidth is quite low, presumably because of the loading introduced by the diodes. The broad-band properties are retained to the extent that, at least for some diode arrangements, the structure can be tuned by varying the pump frequency and power. Thus, for a pump frequency variation of 100 mc, the signal frequency has been moved through an 80-mc range.

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A High Field Effect Two-Terminal Oscillator*

As early as 1953,[1] charge multiplication in reverse biased *p-n* junctions was reported. A rather rigorous treatment by McKay[2] in 1954 prompted additional work by Eber and Miller,[3] Kidd, *et al.*,[4] and many more. Recently Gunn[5] and Yamaguchi and Hammakawa[6] have discussed the negative resistance properties associated with avalanche multiplication. The purpose of this note is to indicate the application of this phenomenon to sinusoidal oscillators using readily available solid-state devices.

It is interesting to note that this breakdown effect can be observed at the collector-base junction of most low-power transistors. A typical volt ampere characteristic for a 2N147 (linear gradient) unit is shown in Fig. 1. Characteristics for both step and linear gradient junctions have been obtained and are quite similar in nature.

The requirement of a negative resistance device in two-terminal oscillators is known,[7] and in an effort to exploit the high field effect more fully, the oscillator of Fig. 2 was constructed. The equivalent of Fig. 2 is shown in Fig. 3, where $-R$ is the average negative resistance value of the junction over the operating range.

Minimum Negative Resistance Requirement

From elementary circuit theory,

$$E_{0(s)} = \frac{sC_1^2[e_1(0^+) - e_2(0^+)] - (g_e + sC_1)[C_1e_1(0^+) - (C + C_1)e_2(0^+)]}{(g_e + sC_1)\left[sC - sC_1 + \frac{1}{R_1} - \frac{1}{R_1^2\left(\frac{1}{sL} + \frac{1}{R_1}\right)}\right] - s^2C_1^2}. \quad (1)$$

From (1) the characteristic equation is

$$s^3LC_1(C_e - C_1) + s^2[Lg_eC_e + R_1C_1C_e - C_1^2R_1] + s[R_1g_eC_e + C_1] + g_e = 0 \quad (2)$$

where

$$g_e = \frac{1}{R_L} - \frac{1}{R}$$

$$C_e = C - C_1.$$

Under the linearized assumptions, a minimum condition for oscillation requires that the conjugate roots of (2) be purely imaginary. Thus (2) is of the form

$$(s + a)(s^2 + \omega^2) = 0 \quad (3)$$

or

$$s^3 + as^2 + \omega^2 s + a\omega^2 = 0. \quad (4)$$

Comparing (4) and (2) yields

$$\omega = \sqrt{\frac{R_1g_eC_e + C_1}{LC_1(C_e - C_1)}}, \quad (5)$$

or a minimum average value of negative resistance is found as

$$|-R| \geqq \frac{R_LR_1(C - C_1)}{R_1(C - C_1) - R_L\omega^2LC_1(C - 2C_1) + R_LC_1}. \quad (6)$$

For the oscillator circuit of Fig. 2, $\omega = 52{,}300$ rad/sec, and

$$|-R| \geqq 1.29 \text{ ohms}.$$

Maximum Negative Resistance Requirement

Assuming $C_1 = C$ and $\omega_{ar}^2 \cong 1/(2CL)$, the Thevenin antiresonant impedance at the *p-n* junction terminals is

$$R_{ar} = \frac{4R_1R_LL}{4R_1L + R_LL + 2R_LR_1^2C}. \quad (7)$$

To satisfy the requirement that the average ac power dissipated by the load resistance and tank circuit be supplied by the negative resistance device places an upper limit on the average value of the negative resistance as

$$|-R| \leqq R_{ar}. \quad (8)$$

For the circuit of Fig. 2,

$$|-R| \leqq 143 \text{ ohms}.$$

Observed waveforms (Fig. 4) indicate that a very low distortion signal may be developed.

A difficulty arises, however, since biasing the device in the negative resistance region causes rather large quiescent currents to flow through the narrow base region. The junction temperature rises, which quite abruptly results in the deterioration of oscillator performance.

In addition to work done with collector-base junctions, an investigation has been

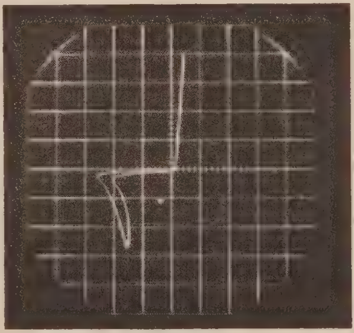

Fig. 1—*P-N* junction volt ampere characteristic. Vertical, 10 ma/cm; horizontal, 10 v/cm.

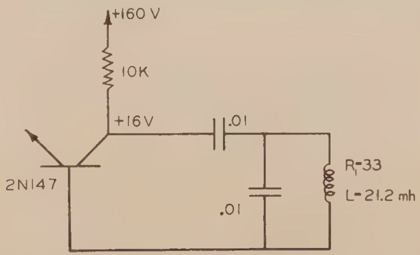

Fig. 2—Schematic diagram of a two-terminal oscillator.

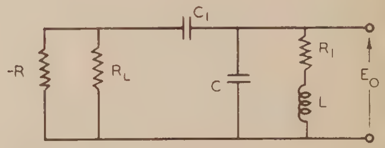

Fig. 3—Equivalent circuit (ac) of Fig. 2.

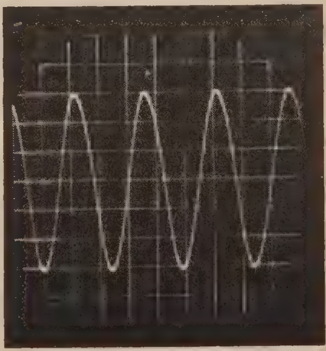

Fig. 4—Oscillator output voltage. Vertical, 2 v/cm; horizontal, 50 μsec/cm.

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* Received by the IRE, January 11, 1960.

[1] K. G. McKay and K. B. McAfee, "Electron multiplication in silicon and germanium," *Phys. Rev.*, vol. 91, pp. 1079–1089; September, 1953.

[2] K. G. McKay, "Avalanche breakdown in silicon," *Phys. Rev.*, vol. 94, pp. 877–884; May, 1954.

[3] J. J. Ebers and S. L. Miller, "Alloyed junction avalanche transistors," *Bell Sys. Tech. J.*, vol. 34, pp. 883–902; September, 1955.

[4] M. C. Kidd, *et al.*, "Delayed collector conduction, a new effect in junction transistors," *RCA Rev.*, vol. 16, pp. 16–33; March, 1955.

[5] J. B. Gunn, "Progress in Semiconductors," John Wiley and Sons, Inc., New York, N. Y., vol. 2, p. 213; 1957.

[6] J. Yamaguchi and Y. Hamakawa, "High electric field effects in germanium *p-n* junction," *J. Phys. Soc. Japan*, vol. 14 pp. 15–21; January, 1959.

[7] A. W. Lo, *et al.*, "Transistor Electronics," Prentice-Hall, Inc., New York, N. Y., p. 368; 1955.

begun which employs commercially available alloyed junction diodes for this application. The usefulness of these units in two-terminal oscillators would be enhanced if lower breakdown voltage devices were available, permitting the use of lower supply voltages.

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Generating a Rotating Polarization*

By relatively simple means, it is possible to generate an arbitrarily-polarized wave whose polarization can be caused to rotate at virtually any desired angular rate. It is well known that any polarized wave can be resolved into components of right- and left-handed circular polarizations, or that any polarization can be constructed from appropriate combination of two oppositely sensed circularly polarized components.

Consider a two-port circularly polarized antenna, one port of which couples to the right circularly polarized mode, and a second port which couples to the left circularly polarized mode of radiation. At microwave frequencies, such an antenna is readily realized by incorporating a quarter-wave plate in a circular waveguide dual-mode transducer as represented in Fig. 1. A signal fed into port A is converted to right circular polarization (RCP) by the device, while a signal fed into port B is converted to left circular polarization (LCP). By controlling the relative phase and amplitudes of inputs to ports A and B, it is possible to generate any desired polarization.

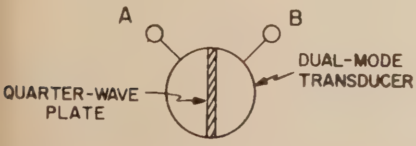

Fig. 1—A two-port circularly polarized antenna.

If signals entering ports A and B (Fig. 1) are the same frequency and equal in amplitude, the two oppositely-sensed CP waves which are generated add vectorally to form a *linearly polarized* wave. The plane of polarization of this linearly polarized wave is determined by the angular phase relationship between the signals entering ports A and B. If signals into ports A and B are made unequal in amplitude, the wave generated by the device will be *elliptically polarized*, and its sense will be determined by the sense of the larger CP component. Thus, the sense and the axial ratio of the resultant wave is controlled simply by varying the ratio of input amplitudes to ports A and B, while the plane of polarization (or orientation of the major axis of the ellipse) is determined by the phase relationship of the two inputs. This simple mechanism, involving just two independent variables, provides complete control of polarization.

As the spatial orientation of the polarized wave is a function of the phase relationship between the right- and left-handed CP components, one can rotate the polarization simply by introducing a relative phase change between the inputs to A and B. By introducing a continuous phase change, as by rotating a continuous type phase shifter, the rotation of polarization can be made continuous. To cause the polarization to rotate at a constant angular rate requires introduction of a constant *rate-of-change-of-phase* between inputs to ports A and B. This, however, amounts to introducing a frequency difference between inputs A and B; hence, to generate a polarized wave which rotates at a constant angular rate, one need only introduce signals at ports A and B which differ in frequency. The relative amplitudes are adjusted to obtain the desired sense and axial ratio, and the frequency difference is chosen to obtain the desired rate of rotation. The rotation frequency will be one-half the frequency difference between inputs to A and B; that is,

$$f_R = \frac{f_A - f_B}{2}.$$

The achievable rate of rotation is limited only by the bandwidth of the RF components.

If one detects this wave by using a linearly polarized antenna, the shape of the modulation envelope would suggest that the transmission was a double-sideband suppressed carrier signal having an effective carrier frequency,

$$f_C = \frac{f_A + f_B}{2}.$$

The RF envelope is the same as would be obtained if a transmitting antenna of the same axial ratio, radiating at frequency f_C, was rotated mechanically about its radiation axis at frequency f_R. For a rotating linear polarization the "sidebands" would be equal in amplitude; for a rotating elliptical polarization, they would be unequal.

In generating a wave having a rotating polarization, a stable rotation rate can be achieved if signals f_A and f_B are derived by using single-sideband generator techniques to develop separate upper and lower sidebands with carrier suppressed.

If one employs a two-mode circularly polarized antenna to receive a wave having a rotating polarization, it follows that the outputs from the RCP and the LCP ports will be at different frequencies, f_A and f_B, in accordance with the equations already given. If the rotating wave is elliptically polarized, this fact will be indicated by amplitude inequality of the two CP outputs.

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* Received by the IRE, January 26, 1960.

A "Z-Transform-Describing-Function" for On-Off Type Sampled-Data Systems*

The study of on-off type control systems with sampled data by means of the describing function technique has been made previously by Chow[1] and Russell.[2] In these early investigations, the nonlinear element for which the describing function is derived includes the sampling switch, the zero-order hold circuit, and the on-off relay. For a sinusoidal input whose period is an integral multiple of the sampling period T, the output of the nonlinear element is a periodic rectangular wave. Thus the conventional describing function technique for continuous systems can be applied directly; the nonlinear sampled data system is essentially treated as a continuous system. The method is subject to limitations that a zero-order hold circuit must be used, and there is only one sampling switch in the system which samples the error signal $e(t)$ (Fig. 1).

The present investigation involves the derivation of a new describing function utilizing the Z transformation. The nonlinear element N in this case includes only the on-off relay. The new describing function permits the study of on-off type sampled-data systems of the following types: 1) systems with or without zero-order hold circuit, 2) finite-pulse-width consideration with flat-topped approximation, and 3) systems with more than one synchronized sampling switch.

The block diagram of the nonlinear system with sampled-data under consideration is shown in Fig. 1. The sampling rate of the sampler is assumed to be uniform and the sampling duration is assumed negligible, *i.e.*, ideal sampler. The operational characteristic of the relay is shown in Fig. 2.

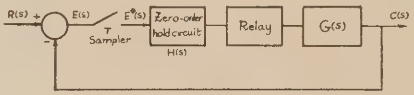

Fig. 1.

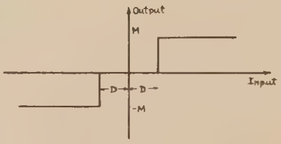

Fig. 2.

If the error signal $e(t)$ is sinusoidal with a period of $T_c = nT$, where T is the sampling period of the sampler, and $n = 2, 3, 4, \cdots$, the output of the sampler $e^*(t)$ is an impulse train of the same period since $e^*(t)$ can have values only at the sampling instants.

As a first step in the study of the system, it is seen that the system behavior is not

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* Received by the IRE, November 16, 1959.

[1] C. K. Chow, "Contactor servomechanisms employing sampled data," *Trans. AIEE*, vol. 73, pt. II, pp. 51–64; March, 1954.

[2] F. A. Russell, "Design Criterion for Stability of Sampled-Data On-off Servomechanisms," Ph.D. dissertation, Columbia University, New York, N. Y.; 1953.

altered if the hold circuit and the relay shown in Fig. 1 are exchanged in position; the modified system is shown in Fig. 3.

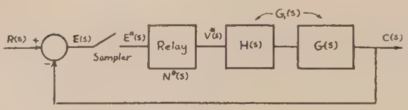

Fig. 3.

It is apparent that the system behavior is not altered by this change. The nonlinear element N in this case contains only the on-off relay. Since the transfer function of the zero-order hold $H(s)$ and $G(s)$ are both linear, the function,

$$G_1(s) = H(s)G(s) = \frac{1-\epsilon^{-Ts}}{s}G(s), \quad (1)$$

is also linear.

The derivation of the describing function $N(z)$ for the relay is based on the assumption that the input signal to the sampler is a sinusoid, and, consequently, the input to N is an impulse train with a sinusoidal envelope. The Z-transform-describing function is defined as the ratio of the Z transform of the output and the Z transform of the input to the relay.

Thus,

the Z-transform describing

$$\text{function } N(z) = \frac{V(z)}{E(z)} \quad (2)$$

where

$$E(z) = Z\text{-transform of } [e(t) = E\cos(at+\phi)]. \quad (3)$$

The output transform of the system shown in Fig. 3 is

$$C(s) = G_1(s)V^*(s) = G_1(s)N^*(s)E^*(s). \quad (4)$$

Thus,

$$\begin{aligned} E(s) &= R(s) - C(s) \\ &= R(s) - G_1(s)N^*(s)E^*(s). \quad (5) \end{aligned}$$

But since

$$E^*(s) = \frac{1}{T}\sum_{n=-\infty}^{\infty} E(s+jnw_s), \quad (6)$$

substituting (5) into (6), we have

$$E^*(s) = \frac{1}{T}\sum_{n=-\infty}^{\infty} [R(s+jnw_s) - G_1(s+jnw_s) \cdot N^*(s+jnw_s)\cdot E^*(s+jnw_s)]. \quad (7)$$

Since for a fixed frequency a, the describing function $N^*(s)$ can be shown to be a linear function of e^{sT},

$$N^*(s) = N^*(s+jnw_s) \quad (8)$$

and it is well known that

$$E^*(s) = E^*(s+jnw_s). \quad (9)$$

Eq. (7) becomes

$$E^*(s) = R^*(s) - G_1^*(s)N^*(s)E^*(s) \quad (10)$$

where

$$R^*(s) = \frac{1}{T}\sum_{n=-\infty}^{\infty} R(s+jnw_s) \quad (11)$$

and

$$G_1^*(s) = \frac{1}{T}\sum_{n=-\infty}^{\infty} G_1(s+jnw_s). \quad (12)$$

Solving for $E^*(s)$ in (10), we get

$$E^*(s) = \frac{R^*(s)}{1+N^*(s)G_1^*(s)} \quad (13)$$

from which

$$\frac{C^*(s)}{R^*(s)} = \frac{N^*(s)G_1^*(s)}{1+N^*(s)G_1^*(s)} \quad (14)$$

or

$$\frac{C(z)}{R(z)} = \frac{N(z)G_1(z)}{1+N(z)G_1(z)}. \quad (15)$$

The study of the condition of self-sustained oscillation of the nonlinear sampled-data system now involves the investigation of

$$G_1(z) = -\frac{1}{N(z)}. \quad (16)$$

In general, if the hold circuit is absent and the finite pulse width has to be considered, the transfer function $H(s)$ can be replaced by

$$H_p(s) = \frac{1-\epsilon^{-ps}}{s} \quad (17)$$

where $p(p \leq T)$ is the pulsewidth (flat-topped approximation).

For a system with feedback element $B(s)$, and a synchronized sampling switch in the feedback path (Fig. 4), the closed-loop transfer function is

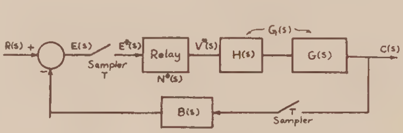

Fig. 4.

$$\frac{C(z)}{R(z)} = \frac{N(z)G_1(z)}{1+B(z)G_1(z)N(z)}, \quad (18)$$

which means that the stability of the system is investigated from

$$B(z)G_1(z) = -\frac{1}{N(z)}. \quad (19)$$

The Derivation of $N(z)$

As an example, the describing function $N(z)$ will be derived for the case when $e(t)$ is a sinusoid of period $T_c=4T$. This means that the relay may have either one or two positive (or negative) corrections during one period T_c. If the number of corrections is designated by Δ (Δ can be either one or two in this case), considering $\Delta=1$, the relay output can be written as

$$\begin{aligned} V(z) &= 1 - z^{-2} + z^{-4} - z^{-6} + \cdots \\ &= \frac{z^2}{z^2+1}. \quad (20) \end{aligned}$$

The Z transform of $e(t) = E\cos(at+\phi)$ is

$$E(z) = \frac{Ez}{z^2 - 2z\cos aT + 1} \cdot [(z-\cos aT)\cos\phi - \sin aT\sin\phi] \quad (21)$$

and for $T_c = T4$,

$$aT = \pi/2, \qquad z = \epsilon^{jwT} = j.$$

Thus,

$$\begin{aligned} N(z) = \frac{V(z)}{E(z)} &= \frac{z^2}{z^2+1} \times \frac{z^2+1}{Ez(z\cos\phi - \sin\phi)} \\ &= -\frac{1}{E} \times \frac{1}{\cos\phi + j\sin\phi}. \quad (22) \end{aligned}$$

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A Note on the Steady-State Response of Linear Time-Invariant Systems to General Periodic Input*

In the following discussion, a simple procedure is presented for obtaining the steady-state response of linear systems to nonsinusoidal periodic inputs. This procedure is based on applying the final value theorem to the modified z-transform of the output. It is known that the modified z-transform method is widely used for the analysis of sampled-data and finite pulsed systems; its use to the above problem is readily evident. A very brief discussion of this method is hereby presented.

Suppose that the Laplace transform of part of the output[1] $C_1(s)$ (which contains only finite poles and has a higher degree denominator in s than numerator) is given. Then its modified z-transform denoted as $C_1^*(z, m)$ is given by the following complex convolution integral.[2]

$$\begin{aligned} C_1^*(z, m)_{z=e}\big|_{Ts} &= Z_m[C_1(s)] \\ &= \frac{e^{-Ts}}{2\pi j}\int_{c-j\infty}^{c+j\infty} C_1(p)\frac{e^{mpT}}{1-e^{-T(s-p)}}\,dp, \\ & \qquad 0 \leq m \leq 1 \quad (1) \end{aligned}$$

where T is the input period.

One method of evaluating the above integral is to integrate around a closed path in the left half of the complex p-plane that encloses all the finite singularities of $C_1(p)$, applying the residue theorem. In this case (1) becomes

$$C_1^*(z, m) = z^{-1}\sum_{\text{poles of } C_1(p)} \text{residue of}\left[C_1(p)\frac{e^{mpT}}{1-e^{pT}z^{-1}}\right]\Bigg|_{z=e^{Ts}}. \quad (2)$$

For instance, if $C_1(s) = 1/s+a$, (2) yields for its modified transform

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* Received by the IRE, December 11, 1959; revised, January 14, 1960.

[1] The Laplace transform of the output in this case can always be represented as

$$C(s) = C_1(s)\frac{1}{1-\epsilon^{-Ts}}.$$

[2] E. I. Jury, "Sampled Data Control Systems," John Wiley and Sons, Inc., New York, N. Y., chs. 2, 9; 1958.

$$C_1^*(z, m) = Z_m\left[\frac{1}{s+a}\right] = \frac{e^{-amT}}{z - e^{aT}}, \quad 0 < m < 1. \quad (3)$$

In the literature, extensive tables of modified z-transform pairs[2,3] are given that can be readily used for more complicated forms of $C_1(s)$. However, in some cases $C_1(s)$ (having simple poles) can be represented by partial fraction expansion as the sum of single time constants. Then its modified z-transform can be readily obtained as the sum of the terms of the form of (3).

The final value theorem developed for the modified z-transform can be briefly stated as follows:[2,3]

$$\lim_{n\to\infty} c(n, m)T = \lim_{z\to 1} \frac{z-1}{z} C^*(z, m), \quad 0 \le m \le 1, \quad (4)$$

if the limit exists where $C^*(z, m)$ is the modified z-transform of the output $C(s)$.

Furthermore, the continuous output in a closed form is also given by the inverse z-transform[2] as follows:

$$c(n, m)T = Z^{-1}[C^*(z, m)] = \frac{1}{2\pi j}\int_\Gamma C^*(z, m)z^{n-1}dz, \quad 0 \le m \le 1$$

$$t = (n - 1 + m)T$$

$$n = \text{positive integer} \quad (5)$$

where Γ is a closed path of integration in the z-plane that enclosed all the poles of $C^*(z, m)$.

For the purpose of this discussion only the final value theorem is applied to obtain the steady-state response. The following two cases are discussed:

Case 1:

$$C(s) = F(s) + C_1(s)\frac{1}{1 - e^{-Ts}}. \quad (6)$$

$F(s)$ in (6) is a rational function of s and has a final value f_{ss} that can be obtained from $\lim_{s\to 0} sF(s)$. Hence, the steady-state output yields

$$c_{ss} = f_{ss} + \lim_{z\to 1}\frac{z-1}{z} Z_m\left[C_1(s)\frac{1}{1-e^{-Ts}}\right] = f_{ss} + \lim_{z\to 1} Z_m[C_1(s)],$$

since

$$Z_m\left[\frac{1}{1 - e^{-Ts}}\right] = \frac{z}{z-1}\bigg|_{z=e^{Ts}}. \quad (7)$$

Case 2:

$$C(s) = F_1(s)\frac{F_2(e^{\tau_n s})}{1 - e^{-Ts}} = C_1(s)\frac{1}{1-e^{-Ts}}; \quad (8)$$

the sum of all τ_n is less than T.

In general the steady-state output of (8) is composed of several regions depending on (τ_n); thus in obtaining the modified z-transform of (8) the several regions should be observed. Mathematically, this indicates that due care should be exercised in observing the convergence of the integral along the infinite semicircle in evaluating (1). This is best illustrated with the given example.

Example a: Consider the steady-state voltage of $v_0(t)$ across the condenser[4] in Fig. 1(a) for an input of the form of rectified sine wave shown in Fig. 1(b).

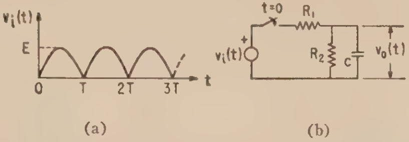

Fig. 1—(a) Rectified sine wave. (b) A parallel RC circuit with series resistance.

$V_0(s)$ in this example equals

$$V_0(s) + \frac{K}{s^2 + (\pi/T)^2}\,\frac{1 + e^{-Ts}}{1 - e^{-Ts}} \times \frac{1}{s+a} \quad (9)$$

where

$$K = \frac{\pi E}{TR_1c}, \qquad a = \frac{R_1 + R_2}{R_1R_2c}.$$

The steady-state voltage is given by

$$V_{0ss} = \lim_{z\to 1} 2KZ_m\frac{1}{[s^2 + (\pi/T)^2][s+a]},$$

since

$$\lim_{z\to 1} Z_m[1 + e^{-Ts}]\,\big|_{z=e^{Ts}} = 2. \quad (10)$$

By using partial fraction expansion of

$$\frac{1}{[s^2 + (\pi/T)^2][s+a]}$$

the modified z-transform can be obtained.[5] The steady-state voltage is obtained by applying the final value theorem.

$$V_{0ss} = \left[\frac{K}{a^2 + (\pi/T)^2}\right]\left[\frac{2e^{-amT}}{1 - e^{-aT}} - \cos \pi m + \frac{aT}{\pi}\sin \pi m\right], \quad 0 \le m \le 1. \quad (11)$$

Example b: This example illustrates the application of the theorem to a periodically varying (cyclic) pulsed system.[6] Obtain the steady-state voltage of $v_R(t)$ across the resistance shown in Fig. 2(a) for a periodically varying (cyclic) input shown in Fig. 2(b).

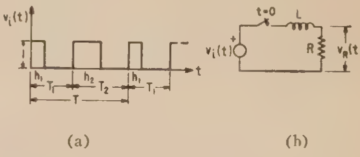

Fig. 2—(a) Periodically time-varying (cyclic) wave. (b) Series RL circuit.

The Laplace transform of the voltage across the resistance, R,

$$V_R(s) = R/L\frac{[1 - e^{-h_1s} + e^{-T_1s}(1 - e^{-h_2s})]}{s(s + R/L)(1 + e^{-Ts})}$$

$$= \frac{[1 - e^{-h_1s} + e^{-T_1s} - e^{-(T_1+h_2)s}]}{s(1 - e^{-Ts})}$$

$$- \frac{[1 - e^{-h_1s} + e^{-T_1s} - e^{-(T_1+h_2)s}]}{(s + R/L)(1 - e^{-Ts})} \quad (12)$$

In this case the steady-state is composed of four regions as follows: I, $0 \le mT \le h_1$; II, $h_1 \le mT \le T_1$; III, $T_1 \le mT \le h_2 + T_1$; IV, $T_1 + h_2 \le mT \le T$. For region I, the modified z-transform yields[7]

$$V_R^*(z, m) = \frac{1 - z^{-1} + z^{-1} - z^{-1}}{(z-1)(1-z^{-1})} - \frac{[1 - e^{-(T-h_1)R/L}z^{-1} + e^{-(T-T_1)R/L}z^{-1} - e^{-(T-T_1-h_2)R/L}z^{-1}]}{(z - e^{-(R/L)T})(1 - z^{-1})}e^{-mTR/L}. \quad (13)$$

The steady-state value

$$v_{ss} = \left[1 - \frac{(1 - e^{-(T-h_1)R/L} + e^{-(T-T_1)R/L} - e^{-(T-T_1-h_2)R/L})}{(1 - e^{-(R/L)T})}e^{-mTR/L}\right], \quad 0 \le mT \le h_1 \quad (14)$$

It is of interest to note that for a fixed pulse-width, $h_2 = 0$, $h_1 = h$, $T_1 = T$, the steady-state voltage

$$V_{ss} = \left[1 - \frac{(1 - e^{-(T-h)R/L})}{1 - e^{-(R/L)T}}e^{-mTR/L}\right], \quad 0 \le mT \le h. \quad (15)$$

For the continuous case, $h_1 = T_1 = T$, $h_2 = T = T_1$, we obtain unity as the steady-state value.

Similarly for regions II, III, and IV the following is obtained for this general case:

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[3] J. Cypkin, "Theory of Pulse Systems," State Press for Physics and Mathematical Literature, Moscow, USSR, ch. 4; 1959.

[4] D. K. Cheng, "Analysis of Linear Systems," Addison Wesley Publishing Co., Inc., Reading, Mass., ch. 7; 1959.

[5] It should be noted that $V_0^*(z, m)$ can also be obtained by the use of available extensive tables to be found in refs. 2 and 3.

[6] E. I. Jury and T. Nishimura, "Analysis of finite pulse systems with periodically varying sampling rate and pulse width," to be published in *Trans. AIEE;* October, 1959.

[7] It should be noted that for region I,

$$Z_m\left[\frac{e^{-h_1s}}{s + (R/L)}\right] = Z_m\left[\frac{e^{-Ts}\,e^{(T-h_1)s}}{s + (R/L)}\right] = \left[z^{-1}\frac{e^{-(T-h_1)(R/L)}}{z - e^{-(R/L)T}}e^{-mTR/L}\right].$$

This stems from the consideration of the convergence of the integral in (1) in the left half of the p-plane (see ref. 2).

$$v_{ss} = 0 - \left(\frac{1 - e^{h_1 R/L} + e^{-(T-T_1)R/L} - e^{-(T-T_1-h_2)R/L}}{1 - e^{-(R/L)T}}\right) e^{-mTR/L}, \quad h_1 \leq mT \leq T_1; \qquad \text{II.} \quad (16)$$

$$v_{ss} = 1 - \frac{\left[1 - e^{h_1 R/L} + e^{T_1 R/L} - e^{-(T-T_1 h_2)R/L}\right]}{1 - e^{-(R/L)T}} e^{-mTR/L}, \qquad T_1 \leq mT \leq T_1 + h_2; \text{ III.} \quad (17)$$

$$v_{ss} = 0 - \left(\frac{1 - e^{h_1 R/L} + e^{T_1 R/L} - e^{(T_1+h_2)R/L}}{1 - e^{-(R/L)T}}\right) e^{-mTR/L}, \qquad T_1 + h_2 \leq mT \leq T; \quad \text{IV.} \quad (18)$$

A plot of v_{ss} for the four regions is shown in Fig. 3.

In conclusion, an alternate[8-10] and in some cases a simpler procedure is introduced in this work than is sometimes used for determining the steady-state response.[4] The procedure is based on assuming that the periodic input is described in time which is Laplace transformable and that the system is stable. It might be also mentioned that the procedure introduced has also been applied to obtain a closed form of an infinite convergent Fourier series.[2]

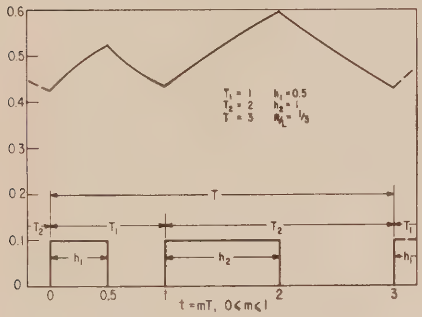

Fig. 3—Steady-state response v_{ss} of voltage in Fig. 2(a).

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[8] C. A. Desoer, "Transmission through a linear network containing a periodically operated switch," 1958 IRE, WESCON Convention, pt. 2, pp. 34–41.

[9] S. Seshu and N. Balabanian, "Linear Network Analysis" (book), John Wiley and Sons, Inc., New York, N. Y., ch. 5; 1959.

[10] A. Fettweis, "Steady-state analysis of circuits containing a periodically-operated switch," IRE Trans. on Circuit Theory, vol. CT-6, pp. 252–260; September, 1959.

WWV and WWVH Standard Frequency and Time Transmissions*

The frequencies of the National Bureau of Standards radio stations WWV and WWVH are kept in agreement with respect to each other and have been maintained as constant as possible with respect to an improved United States Frequency Standard (USFS) since December 1, 1957.

The nominal broadcast frequencies should, for the purpose of highly accurate scientific measurements, or of establishing high uniformity among frequencies, or for removing unavoidable variations in the broadcast frequencies, be corrected to the value of the USFS, as indicated in the table below.

The characteristics of the USFS, and its relation to time scales such as ET and UT2, have been described in a previous issue,[1] to which the reader is referred for a complete discussion.

The WWV and WWVH time signals are also kept in agreement with each other. Also they are locked to the nominal frequency of the transmissions and consequently may depart continuously from UT2. Corrections are determined and published by the U. S. Naval Observatory. The broadcast signals are maintained in close agreement with UT2 by properly offsetting the broadcast frequency from the USFS at the beginning of each year when necessary. This new system was commenced on January 1, 1960. The last time adjustment was a retardation adjustment of 0.02 *s* on December 16, 1959.

WWV Frequency
With Respect to U. S. Frequency Standard

1960 February 1600 UT	Parts in 10^{10}†
1	−145
2	−145
3	−145
4	−145
5	−145
6	−145
7	−145
8	−144
9	−144
10	−145
11	−145
12	−145
13	−145
14	−146
15	−146
16	−146
17	−147
18	−147
19	−147
20	−147
21	−147
22	−147
23	−147
24	−147
25	−146
26	−146
27	−146
28	−146
29	−146

† A minus sign indicates that the broadcast frequency was low.

National Bureau of Standards
Boulder, Colo.

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* Received by the IRE, March 28, 1960.

[1] "United States National Standards of Time and Frequency, Proc. IRE, vol. 48, pp. 105–106; January, 1960.

Electronically-Variable Phase Shifters Utilizing Variable Capacitance Diodes*

In many applications which require electronically-variable phase shifters for operation in the UHF and microwave region, ferrite devices or traveling-wave tubes are not suitable because of excessive weight, size, or demand for control power. The use of variable capacitance diodes for high-frequency phase shifting has been under study for more than a year and has resulted in a compact, fast, and efficient electronically-controlled phase shifter. On the debit side, the device is at present useful only at lower power levels and also has limited phase shift-bandwidth product.

If a transmission line is terminated in a pure reactance, all the energy incident upon the termination is reflected and the phase shift of the reflected wave is a function of the magnitude of the reactance. When the reactive termination is used in a circuit which completely separates the incident and reflected waves (circulator or a properly phased balanced circuit), a variation in the terminating reactance will produce a change in the phase of the reflected output wave and the complete unit will be well matched and efficient.

In practice, two variable capacitance diode terminations have been used with hybrid rings, hybrid junctions, and certain types of 3-db couplers. One of the simplest configurations results if the coupling circuit is a waveguide short-slot coupler or its coaxial or stripline equivalent, as shown in Fig. 1. The phase of the output wave varies as the bias voltage on the diodes is changed. Stripline techniques permit miniaturization, and very little control power is required because of the high reverse impedance of the diodes. Some RF loss is introduced by the spreading resistance of the diodes, but this is not serious if the diode has reasonably high Q.

In this circuit, the rate of change of phase shift with reactance is greatest at $X=0$. Therefore, for maximum phase shift, the diode termination should be adjusted for resonance in the center of the diode's capacity variation range. This can be done by properly adjusting "stubs" behind the diode. Maximum insertion loss also occurs at resonance, so phase shift can be traded, to some extent, for decreased insertion loss.

Phase shifters utilizing variable capacitance diodes have been constructed at 0.5, 1.0, 6.0, and 9.0 kmc. A phase shift of over 180° was obtained with a single unit at 1 kmc, 110° at 6 kmc, and 41° at 9 kmc. Maximum insertion lose varied from 1.2 db at 1 kmc to 3.9 db at 9 kmc, although the latter figure was improved considerably by decreasing phase shift. Fig. 2 shows the phase-shift and insertion-loss variation with bias voltage at 1 kmc.

The data was obtained at a power level of 1 milliwatt using Hughes Products (HPA 2800) diodes. These diodes have a capacity variation from about 2.5 to 1.0 $\mu\mu f$ with a bias voltage change from 0 to 5 volts; the reverse breakdown voltage is about 7

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* Received by the IRE, August 24, 1959.

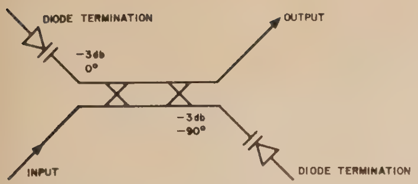

Fig. 1—A variable capacitance diode phase shifter using a 3-db coupler.

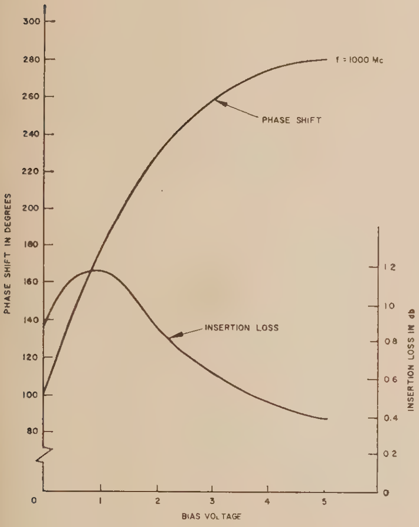

Fig. 2—Phase shift and insertion loss as a function of diode bias at 1 kmc.

volts. The insertion loss of phase shifters using these diodes increases with RF power; at 20 mw, for example, the loss is 6.4 db. This rapid increase in loss at higher powers results in a limiting action and is caused by power lost in harmonic generation and because of the onset of both forward and backward diode conduction.

In order to increase the operating power level of the phase shifter, a high-Q variable capacitance diode with a high reverse breakdown voltage is needed. This feature would permit higher RF voltages without driving the diode into conduction, and harmonic generation would be reduced because the capacity variation with voltage would be decreased. Unfortunately, high reverse breakdown voltage and small spreading resistance are somewhat incompatible. However, some improvement over parametric amplifier diodes is possible and further development may improve the power handling capability of the phase shifter. The phase-shift bandwidth product can be increased by the use of several diodes in a traveling-wave circuit.

The diode phase shifter is a compact and very fast device requiring negligible control power. It may be useful in electronically-scanned receiving arrays, in low power satellite transmitting arrays and in many other applications.

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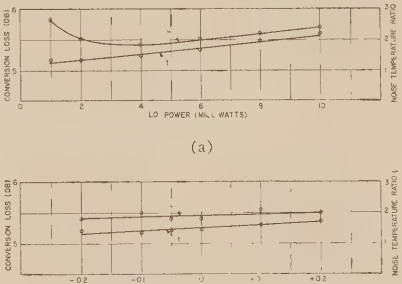
Gallium Arsenide Microwave Diode at *X* Band*

J. J. Wysocki of RCA has kindly supplied us with five of the GaAs microwave diodes described by Jenny[1] in order that we might make measurements at X band.

The measurements were made at 9375 mc and the diodes were matched to the local oscillator. As originally received, the diodes performed rather poorly; typical values of conversion loss L and noise temperature ratio t were 7 db and 3 times, respectively.

The diodes were then rebuilt by resetting the whisker on the crystal so as to maximize the short-circuit rectified current produced by the local oscillator. Fig. 1 gives the results for a *typical* rebuilt crystal. Note the lack of bias dependence [Fig. 1(b)]. The best diode (of approximately 15 resets) had an L of 5.6 db and a t of 1.14 times.[2]



(a)

(b)

Fig. 1—Performance of typical GaAs microwave diode at X band. (a) The dc voltage bias is constant at zero volts. (b) The *LO* power is constant at four milliwatts.

Thus it appears that GaAs diodes can be made with L and t at X band which compare favorably with silicon and germanium diodes. In addition, they are less bias sensitive than germanium diodes and, judging from band-gap data, are promising for high temperature applications.

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* Received by the IRE, September 14, 1959.

[1] D. A. Jenny, "A gallium arsenide microwave diode," Proc. IRE, vol. 46, pp. 717–722; April, 1958.

[2] W. M. Sharpless, "High-frequency gallium arsenide point contact rectifiers," *Bell Sys. Tech. J.*, vol. 38, pp. 259–269; January, 1959.

A Wide Band Phase Shifter*

One of the several applications which require a network giving a 90° phase shift over a wide band of frequencies is the phase-cancelling method of single sideband generation.[1] There are various networks which give an almost constant phase shift of 90° over the audio band.[2]

The arrangement here described achieves the same end in a novel way. It provides exactly 90° phase shift over a bandwidth determined by the characteristics of the filters used in it.

The signal is mixed in a balanced mixer [① in Fig. 1] with a local oscillation (f_0) of higher frequency than the highest modulation frequency used. Of the various combinations and harmonics that result, the upper sideband is selected by a filter. This sideband is then demodulated in each of two balanced mixers [② and ③ in Fig. 1] by mixing again with (f_0) in one case, and by mixing with (f_0) shifted through 90° in the other. Of the resulting combinations and harmonics, the lower sideband is selected in each case, giving the original signal at two outputs differing in phase by 90°. The action should be clear from the diagram.

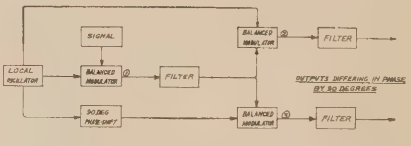

Fig. 1—90° phase shifter.

After mixing in mixer ①, the lower sideband could have been used but in this case, the signal voltage appearing in the modulator output because of lack of balance will not be attenuated in the subsequent filter since this would have to pass frequencies of the same order. This could then be obviated only by raising the local oscillator frequency to a value of at least twice the highest modulation frequency used. This would be undesirable since it would render the separation of desired frequencies close to the local oscillator frequency more difficult.

Band-pass filters would be better than high-pass or low-pass filters because of the presence of harmonics and various other undesired combination frequencies resulting from the modulators. Since the powers involved are quite low, the same techniques can be used as in carrier telephony, whereby simple rectifier modulators may be used, simplifying the apparatus. Clearly, any other desired constant phase shift may be obtained by varying the phase of (f_0) supplied to modulator ③.

Experiments carried out indicate that the method gives the results expected.

Very sincere thanks are due Dr. F. Tank for his constant encouragement and for all the facilities which he has made available.

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* Received by the IRE, October 28, 1959.

[1] O. G. Villard, Jr., "A high level single sideband transmitter," Proc. IRE, vol. 36, pp. 1419–1425; November, 1948.

[2] R. B. Dome, "Wideband phase-shift networks," *Electronics*, vol. 19, pp. 112–115, December 1946; H. J. Orchard, "Synthesis of wideband two-phase networks," *Wireless Engr.*, vol. 27, pp. 72–81, March, 1950; and vol. 28, p. 30, January, 1951.

Bandwidth of Lower Sideband Parametric Up-Converters and Parametric Amplifiers*

In an article by Rowe,[1] an expression is derived for the gain of a lower-sideband up-converter as a function of a stability factor α and a frequency factor x. Because of the complexity of this expression, the bandwidth of the device as a function of α could not be expressed in closed form. A simplified form of the expression allows the bandwidth to be expressed directly as a function of α, thereby permitting evaluation of the bandwidth and the $(\text{gain})^{1/2}$-bandwidth product for any value of gain from zero to infinity.

In Rowe[1] an expression for the conversion gain from IF to the lower side frequency was given as follows:[2]

$$G_{tl-} = \frac{f_{-m}}{f_{lm}} \frac{4\alpha}{(1-\alpha)^2} \frac{1+x^2}{1+\dfrac{(3+\alpha^2)}{(1-\alpha)^2}x^2+\dfrac{(3+2\alpha)}{(1-\alpha)^2}x^4+\dfrac{1}{(1-\alpha)^2}x^6}, \qquad (1)$$

where

α = a stability factor,
x = the relative frequency deviation,
f_{lm} = the IF, at midband, and
f_{-m} = the lower side frequency at midband.

The down-conversion gain is identical to the above expression except that the ratio f_{lm}/f_{-m} replaces the ratio of f_{-m}/f_{lm}.

The bandwidth of the system is proportional to x_0, where x_0 is the value of x which causes the gain to drop 3 db below its midband ($x=0$) value. It was stated by Rowe[1] that the value of x_0 as a function of α could not be found in closed form; therefore, two special cases were selected for calculating the bandwidth.

In a separate derivation, the writer of this letter, by a different approach from that used by Rowe, arrived at

$$G_{tl-} = \frac{f_{-m}}{f_{lm}} \frac{4\alpha}{(1-\alpha)^2} \cdot \frac{1}{1+\dfrac{(2+2\alpha)}{(1-\alpha)^2}x^2+\dfrac{1}{(1-\alpha)^2}x^4}. \qquad (2)$$

In seeking compatibility between this expression and that obtained by Rowe, it was found that the numerator of Rowe's expression is a factor of the denominator, and that (1) and (2) are identical.

To find x_0,

$$\frac{1}{(1-\alpha)^2}x^4 + \frac{2+2\alpha}{(1-\alpha)^2}x^2 = 1,$$

must be solved for x. The two real roots are

$$x_0 = \pm\left[\sqrt{2(1+\alpha^2)} - (1+\alpha)\right]^{\frac{1}{2}}. \qquad (3)$$

For α very near unity this reduces to

$$x_0 \approx \pm \tfrac{1}{2}(1-\alpha)$$

which agrees with Rowe's result.

From (3) the bandwidth and $(\text{gain})^{1/2}$-bandwidth product of the up-converter may be found directly as a function of all values of α for $0 \leq \alpha < 1$, where $\alpha = 1$ represents the threshold of oscillation.

If the negative admittance at the IF or lower side frequency port is used to give gain by reflection, it develops that when the gain is large compared to unity, the same frequency characteristics apply.

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* Received by the IRE, July 10, 1959.

[1] H. E. Rowe, "Some general properties of nonlinear elements. II. Small signal theory," Proc. IRE, pp. 851–860; May, 1958.

[2] *Ibid.*, (59).

Noise Measurements on an *M*-Type Backward-Wave Amplifier*

Up to the present time, full utilization of crossed-field amplifiers has not been realized because of the high level of noise output associated with these devices. The noisiness of the crossed-field beam is usually accompanied by large electron currents collected on an electrode, known as the sole, even when it is biased negatively with respect to the cathode. This aspect of the noise behavior has been extensively studied but is not yet fully understood.[1] The purpose of this letter is to report noise measurements that have been made on an experimental *M*-type backward-wave amplifier. A schematic diagram of the electrode configuration of the device is presented in Fig. 1. The unique feature of this tube is the electron gun design which is based on an analysis by Kino and Kirstein.[2,3] The gun is designed to produce a well-defined, space-charge limited, laminar-flow electron beam with negligible rippling and spread as the beam drifts to the collector. Such beam behavior has been visually observed and is accompanied by negligible sole current. The area convergence of the electron gun is four to one resulting in a beam whose thickness is one-seventh of the line-sole spacing. The width of the beam is approximately one-half that of the sole. An oxide cathode is used in the gun.

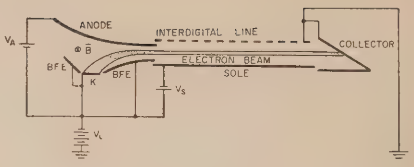

Fig. 1—Schematic of experimental crossed-field backward-wave amplifier.

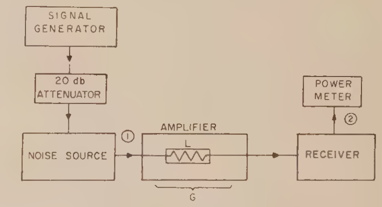

Fig. 2—Experimental arrangement for noise figure measurements.

Three types of noise measurements have been performed: 1) noise figure, 2) signal-to-noise ratio, 3) velocity spread. A block diagram of the basic arrangement for measuring the noise figure is shown in Fig. 2. Under the conditions that the bandwidth of the receiver is much less than the bandwidth of any of the other components and that the impedance of the noise source as seen by the backward-wave amplifier is matched, the noise figure of the amplifier is expressed as,

$$\text{N.F.} = \frac{1}{G}\left[\frac{\left(\dfrac{P_{2\text{on}}}{P_r}-1\right)}{\left(\dfrac{P_{2\text{off}}}{P_r}-1\right)}\left(\frac{P_{ns}}{LP_1}\right)+1\right]$$

where

P_{ns} = noise source output power in excess of thermal noise.
$P_1 = kTB$, the thermal noise input to the tube under matched conditions.
$P_{2\text{off}}$ = power delivered to the power meter with the electron beam off and the noise source on.
$P_{2\text{on}}$ = power delivered to the power meter with the electron beam on and the noise source off.
P_r = noise power at the receiver with both electron beam and noise source off.
G = amplifier gain.
L = input power/output power is the cold loss through the amplifier.

The results of the measurements are presented in Table I. Accuracy of the noise figure is ±2 db, and the 3-db bandwidth of the amplifier is 0.9 per cent of the signal frequency. The dc beam transmission to the collector during these measurements was between 88 and 92 per cent. The receiver bandwidth was 300 kc.

Signal-to-noise ratio measurements were performed for a variety of operating conditions but all with a well-focused electron beam at space-charge limited emission. No distinct coherent sidebands were observed at any appreciable level above the noise output of the tube within a 40-mc band cen-

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* Received by the IRE, September 28, 1959; revised, October 1, 1959. This work was supported by the Signal Corps, under Contract DA 36–039 SC-74981.

[1] R. P. Little, H. M. Ruppel and S. T. Smith. "Beam noise in crossed electric and magnetic fields," *J. Appl. Phys.*, Vol. 29, p. 1376; September, 1958.

[2] T. Midford and G. S. Kino, "Crossed-field electron guns," presented at the 17th Annual Conf. on Electron Tube Research, Mexico City, Mex.; June 24 1959.

[3] P. T. Kirstein, "On the determination of the electrodes required to produce a given electric field distribution along a prescribed curve," Proc. IRE, Vol. 46, pp. 1716–1722; October, 1958.

TABLE I

Tube Parameters	Frequency (mc)	Cathode Emission	Noise Figure (db)
Gain $=15.5$ to 23.8 db $I_{\text{cathode}}=35$ ma $B=125$ gauss Pressure $=5\times10^{-7}$ mm Hg	800	space-charge limited	30.4
	850	space-charge limited	30.6
	875	space-charge limited	35.0
	900	space-charge limited	36.6
Gain $=10$ db $I_{\text{cathode}}=10$ ma $B=135$ gauss Pressure $=5\times10^{-7}$ mm Hg	800	space-charge limited	27.3
	800	temperature limited	24.3

TABLE II

Frequency (mc)	Cathode Current (ma)	Input Power Level (dbm)	Gain (db)	Signal/Noise (db)
870	40.7	36.6 (tube saturated, output $=15$ watts cw)	5	65
790	30.0	8.8	9	50
795	45.0	-0.2	11	48
785	30.0	-51.4	16	40

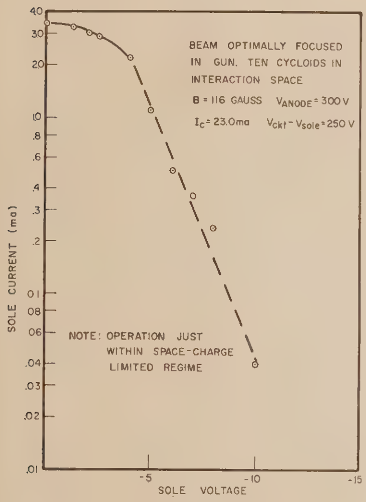

Fig. 3—Sole current distribution.

tered about the signal frequency. The results of these measurements are summarized in Table II. The measured signal-to-noise ratios are in the same range as has been reported for a forward-wave M-type amplifier.[4] The significance of the results presented in Table II is that this type of amplifier can maintain good sensitivity over an extremely wide range of input signal level.

Finally, a few measurements of the velocity spread in the electron beam have been achieved. For space-charge limited conditions and a well-focused beam in the gun region, the line-sole electric field was decreased so that the beam path in the drift region came close to the sole. The beam thickness remained approximately constant throughout the drift region. The velocity spread in the beam can then be estimated from the sole current-sole voltage distribution. This distribution was found to be not half-Maxwellian, as can be seen in Fig. 3. However, the distribution is approximately half-Maxwellian at low sole currents and on this basis, the equivalent temperature of the electron beam is 40,900°K. This corresponds to a decrease of sole current by a factor e at a sole potential of -1.5 volts. From these measurements, it is concluded that even with an electron gun which produces a well-focused laminar beam the characteristic energy spread of crossed-field tubes is still present, although perhaps to a lesser extent than in similar tubes employing less well-behaved beams.

However, the noise figure and signal-to-noise ratio of this M-type backward-wave amplifier has been measured and is found to be of the same magnitude as in O-type tubes when attention was first directed toward their noise problem. No attempt was made to design the present tube for low noise output. Therefore, it is entirely possible that the noise figure of an M-type backward-wave amplifier, utilizing a well-behaved beam, can be reduced further.

The helpful discussions and assistance of C. K. Birdsall, H. L. Jory, T. Van Duzer, and J. R. Whinnery are gratefully acknowledged.

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[4] O. Doehler, A. Dubois, and D. Maillart, "An M-type pulsed amplifier," *Proc. IEE*, part B, suppl. no. 10, vol. 105, pp. 454–457; May, 1958.

On the Start Oscillation of the O-Type Backward Wave Oscillator*

The conditions that the O-type backward wave oscillator satisfy at the start of oscillation are such that θ and CN satisfy the following:

$$\eta^3-2\theta\eta^2+(\theta^2-H^2)\eta+(2\pi CN)^3=0, \quad (1)$$

where the roots of (1), η_1, η_2, and η_3 must satisfy

$$\frac{\eta_3-\eta_2}{\eta_1}e^{j\eta_1}\cos 2+\frac{\eta_1-\eta_3}{\eta_2}e^{j\eta_2}+\frac{\eta_2-\eta_1}{\eta_3}e^{\eta_3}=0;$$

and

$\theta=(\beta_c-\beta_e)L,$
$H=\omega_pL/u_0,$
$CN=$the CN parameter of Pierce's,
$\beta_c=$propagation constant of the unperturbed circuit wave,
$\beta_e=\omega/u_0,$
$u_0=$electron drift velocity,
$L=$length of interaction space,
$\omega_p=$plasma frequency of the beam,
$\omega=$tube oscillation frequency.

Among the various discussions of the solutions of (1), Heffner[1] gave the numerical values of θ corresponding to the first two oscillation modes (designated $n=0$ and 1 modes) for values of H ranging from 0 to 10. Gould[2] further gave the asymptotic solutions for $H\gg1$ in the terms of a coupled-mode theory. Physically, this corresponds to the asymptotic case in which the space charge density of the electron beam is so high that the propagation constants of the unperturbed slow and fast space-charge waves are far enough apart that the fast space-charge wave can be neglected in so far as the interaction between the slow space-charge wave and the backward circuit wave is concerned. Heffner's and Gould's results are reproduced in Fig. 1.

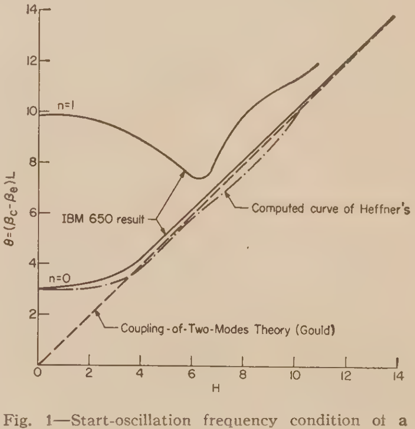

Fig. 1—Start-oscillation frequency condition of a matched backward-wave oscillator.

In connection with a recent study of some anomalous behavior of backward-wave oscillators, we had the occasion to obtain the solution of (1) on the IBM 650 computer.[3] The result thus obtained (see Fig. 1) showed an interesting disagreement with Heffner's result. Although the quantitative discrepancy is small, the physical meaning of this discrepancy seems significant. It is noticed that for the lowest mode ($n=0$), Heffner's curve intersects the asymptotic two-wave solution of Gould at $H\approx3.5$. For $H>3.5$ the value of θ according to Heffner's result becomes less than the asymptotic solution. The

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* Received by the IRE, August 13, 1959.

[1] H. Heffner, "Analysis of the backward-wave traveling-wave tube." Proc. IRE, vol. 42, pp. 930–937; June, 1954.

[2] R. W. Gould, "A coupled mode description of the backward-wave oscillation and the Kompfer dip condition," IRE Trans. on Electron Devices, vol. ED-2, pp. 37–42; October, 1955.

[3] Details are available in C. L. Tang, "Backward Wave Oscillator Mismatching and Spurious Oscillations," Res. Div., Raytheon Mfg. Co., Waltham, Mass., Rept. No. R-42; 1959.

curve corresponding to the IBM 650 result, however, lies above the asymptotic two-wave solution for all values of H and asymptotically approaches the latter from above as H increases. In view of the previous discussion about the physical meaning of the solutions of (1) and the asymptotic two-wave solution of Gould, the implication of the discrepancy is immediately clear. Our result indicates that the effect of the fast space-charge wave on the interaction of the slow space-charge wave and the backward circuit wave is largest when the phase velocities of the three waves are the closest, or H is small. As H increases, or as the phase velocity of the fast space charge wave becomes increasingly faster than the synchronous phase velocity of the circuit wave and the slow space-charge wave, the interaction between the latter two is affected less and less by the fast space-charge wave. Such an effect is, however, always present.

Heffner's result indicates, on the other hand, that the effect of the fast space-charge wave on the interaction of the circuit wave and the slow space-charge wave is opposite for $H<3.5$ and $H>3.5$. (θ increases or decreases for $H<$ or $H>3.5$, respectively, because of the presence of the fast space-charge wave.) At $H\approx 3.5$, the fast space-charge wave has no effect on the interaction of the circuit wave and the slow space-charge wave in so far as θ (or, equivalently, the tube oscillation frequency) is concerned. On purely intuitive grounds, it seems also that our IBM 650 result is the more reasonable of the two.

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Negative Resistance in Transistors Based on Transit-Time and Avalanche Effects*

In this communication, we propose a simple semiconductor device which should exhibit a negative resistance characteristic at frequencies of the order of the carrier inverse transit time in the space-charge or depletion region of a reverse-biased p-n collector junction. Previously, others have proposed negative resistance structures using transit-time effects[1] or both transit-time effects and avalanche multiplication.[2] We also use the latter combination in our device. Our device, structurally speaking, is identical to a transistor; however, it requires a rather small collector capacity and extrinsic base resistance.

The basic idea underlying its operation is as follows: Consider a grounded-base transistor biased at the emitter with a direct current source which produces the usual minority carrier distribution in the base region. The collector junction is reverse biased. The collector-base terminals are the two terminals at which the active impedance is to be produced. Suppose, now, that an alternating voltage of high frequency (far exceeding the α-cutoff) is applied to the collector. In response to this, the boundaries of the collector space-charge region will pulsate in position at the same frequency. We are interested in the base-side edge only. Because of the oscillation of the latter, the injected emitter minority current entering the space-charge region and flowing to the collector is modulated at the plane of the space-charge boundary. If the frequency and amplitude are high enough, the minority carriers will fail to follow the moving space-charge edge and the above current will actually be "bunched." For the small signal case, however, only a sinusoidal modulation of the direct current will be produced. We consider the latter case in this communication. For a suitably chosen collector bias voltage, near avalanche breakdown, this alternating component of particle current, when it arrives at the collector junction, will give rise to an additional (multiplied) particle current consisting of the opposite type carrier. This multiplied component will dominate the injected component in magnitude when the avalanche multiplication factor exceeds two. Because of the finite carrier transit time through the space-charge region (from the edge to the junction plane), there will be frequencies at which the multiplied particle current (or a component of it) is 180° out of phase with the collector signal. At these frequencies, a negative resistance will be produced which may be utilized in amplifiers and oscillators.

Outline of Analytic Treatment

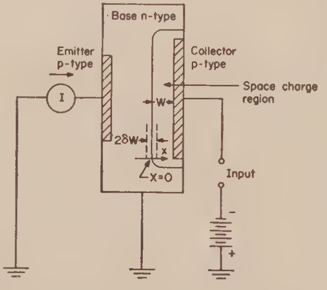

Fig. 1—Schematic presentation of device.

Fig. 1 shows a schematic sketch of a p-n-p alloyed transistor which will serve as our model. Denote the width of the space-charge region in the base- or n-region by W and let the amplitude of its boundary modulation produced by an applied collector signal be called δW. We assume that at the instantaneous edge of this boundary, the injected hole density produced by the emitter bias current is approximately zero. An approximate solution of the diffusion equation in the base region gives

$$p(x) = -\frac{J_{\mathrm{dc}}}{qD}x - \frac{J_{\mathrm{dc}}\delta W}{qD} \cdot \exp\left(\sqrt{\frac{\omega}{2D}}(1-i)x\right)\exp - i\omega t. \quad (1)$$

In (1), $J_{\mathrm{dc}}=I_{\mathrm{dc}}/A$ is the density of the injected minority carrier current I_{dc} entering the space-charge region, where A is the cross-sectional area. In the usual notation, q is the electronic charge, D the diffusion constant of holes, ω the frequency, and t is the time.

From (1), one obtains the alternating particle current density j_i entering the space-charge region at approximately $x=0$

$$j_i = -qD\left.\frac{\partial p}{\partial x}\right|_{x=0} = J_{\mathrm{dc}}\delta W\sqrt{\frac{\omega}{D}}\exp\left(-\frac{i\pi}{4}\right)\exp(-i\omega t). \quad (2)$$

This particle current gives rise to a space-charge wave which travels to the collector junction and produces an additional multiplied component consisting of electrons which travel back in the reverse direction. Assuming that the multiplication takes place at the collector junction plane $x=W$ and that the drift velocity is constant and saturated at a constant value v, then the space-charge wave is given by

$$\rho(x) = \frac{j_i}{v}\left[\exp ikx - \overline{m}\exp - ik(x-2W)\right] \cdot \exp - i\omega t \quad (3)$$

where $k=\omega/v$, $\bar{m}=m-1$, and m is the avalanche multiplication factor.

The calculation proceeds now as follows: Using Poisson's equation, we can obtain from (3) an additional voltage developed across the space charge. For the integration we assume zero electric field at the base-side edge of the space-charge region. We also assume that ρ, as given by (3), is small as compared to the built-in space charge resulting from the ionized donor atoms. We designate this additional voltage by V_{particle}. Similarly, we can calculate an additional current density j_{particle} consisting of the true particle current and a displacement current. Since it is immaterial where this current is calculated, we chose the plane $x\approx 0$. At this plane, the additional displacement current vanishes. The total impedance looking into the base-collector terminals thus may be written

$$Z = \frac{1}{A}\,\frac{V_{\mathrm{displacement}} + V_{\mathrm{particle}}}{j_{\mathrm{displacement}} + j_{\mathrm{particle}}} \approx \frac{V_{\mathrm{displacement}}}{j_{\mathrm{displacement}}A} + \frac{V_{\mathrm{particle}}}{j_{\mathrm{displacement}}A} - \frac{V_{\mathrm{displacement}}\,j_{\mathrm{particle}}}{(j_{\mathrm{displacement}})^2 A}. \quad (4)$$

In (4), $V_{\mathrm{displacement}}$ and $j_{\mathrm{displacement}}$ are the voltage and the current density which would be produced in the absence of any injected current by the oscillating space-charge edge. In the expansion (4), which holds for sufficiently small injected current, the first term is simply the usual space-charge capacitive

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* Received by the IRE, August 27, 1959; revised, October 2, 1959.

[1] W. Shockley, "Negative resistance arising from transit time in semiconductor diodes," *Bell Sys. Tech. J.*, vol. 33, pp. 799–826; July, 1954.

[2] W. T. Read, Jr., "A proposed high-frequency, negative-resistance diode," *Bell Sys. Tech. J.*, vol. 37, pp. 401–446; March, 1958.

term of the collector junction $(-i\omega\epsilon A/W)^{-1}$, which is purely reactive. The remaining two terms are contributions of the injected mobile charge. By carrying out the above outlined integration, we obtain from these latter two terms the additional impedance

$$Z_{\text{add}} = \frac{I_{\text{dc}}W^3}{A^2\sqrt{D\tau\epsilon v^2\rho_f}}\left\{\frac{\exp\left(-i\frac{\pi}{4}\right)}{\sqrt{\omega\tau}} \cdot\left[\frac{(\exp i\omega\tau - 1)}{i(\omega\tau)^2}(\exp i\omega\tau)\right]\right\}. \quad (5)$$

The quantity in the curly brackets denoted $f(\omega\tau)$, is plotted in Fig. 2 as a function of $\omega\tau$ for $\bar{m}=1$ and $\bar{m}=2$. It is seen that at approximately $\omega\tau=0.8\pi$ and $\bar{m}=2$ there is a negative resistance region. The magnitude of the negative resistance, according to (5), obviously increases linearly with bias current.

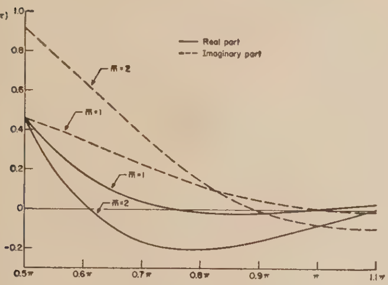

Fig. 2—Real and imaginary parts of $f(\omega\tau)$.

Table I, below, summarizes the results of a calculation of the real and imaginary parts of Z at $\omega\tau=0.8\pi$ for two arbitrary cases for a germanium structure. To get the actual impedance of an idealized three-dimensional structure, one must add to Z the extrinsic base resistance r_b'. Thus for values of $r_b'<96$ ohms, a negative real part wil be exhibited by the structure of Case I.

TABLE I
SEVERAL EXAMPLES OF Z COMPUTED FOR GERMANIUM

	Case I	Case II
Base resistivity n-type (ohm-cm)	2.5	0.35
Donor density (cm^{-3})	7×10^{14}	5×10^{15}
Avalanche breakdown (volts)	200	40
Collector bias (volts)	180	36
Avalanche multiplication factor m	3	3
Space-charge width W (cm)	2×10^{-3}	3.3×10^{-4}
Transit time τ (sec)	3×10^{-10}	5×10^{-11}
Frequency at which $\omega\tau=0.8\pi$ (kmc)	1.3	7.8
Bias current I_{dc} (ma)	0.6	2.5
Collector diameter (cm)	1.25×10^{-2}	5×10^{-3}
Negative resistance (ohms)	−96	−24
Capacitive reactance (ohms)	1500	160

There remains one additional point to investigate, namely, the effect of the modulation of the avalanche multiplication factor m by the varying collector voltage. Since m is voltage dependent, an additional alternating component of space-charge current will be generated at the collector junction by the interaction of the bias current I_{dc} and the time-varying m. It can be shown rather straightforwardly that this contributes a term to Z given by

$$Z_{\text{multiple}} = \frac{W^4 I_{\text{dc}}\left(\frac{dm}{dV}\right)}{\epsilon^2 v^2 A^2}\,\frac{(\exp i\omega\tau - 1)}{i(\omega\tau)^3}. \quad (6)$$

This term, however, contributes a positive real part at $\omega\tau=0.8\pi$. Putting in numbers for the two examples illustrated previously, we obtain real parts of 33 ohms and 20 ohms for Cases I and II, respectively. It is seen that for the higher-frequency example, the positive resistance becomes rather large and almost compensates the calculated negative resistance.

It should be mentioned at this point that one may use, however, only Z_{multiple} of (6) in a sample in which the space-charge boundary is not allowed to oscillate. Such a case is practically found in diffused base transistors. Then, $\omega\tau$ has to be chosen to lie in a range between π and 2π. For a given current level, the amount of negative resistance obtainable is smaller than the values quoted in Table I.

DISCUSSION

It appears entirely possible to obtain a negative resistance at microwave frequencies with transistor-like structures using a combination of avalanche multiplication and transit-time effects. It is quite feasible in practice to realize low enough extrinsic base resistances which will not mask the calculated negative resistance effect. The carrier diffusion time through the neutral part of the base region is unimportant in the proposed device.

The required dc power levels, because of the rather high collector bias voltages needed (near avalanche breakdown) and relatively large currents, are of the order of a fraction of a watt for the examples cited. Provisions for rapid heat dissipation are therefore required. A decrease in this power requirement can be had, of course, by a reduction in the area, but only at the expense of a higher impedance level. For one of the examples discussed, Case I, a desirable impedance level was attained at 1300 mc with a collector diameter of 1.25×10^{-2} cm (5 mils). Higher-frequency units naturally require smaller diameters.

The use of avalanche multiplication unfortunately restricts the allowable voltage amplitude at the collector for linear operation. In addition, the avalanche mechanism is known to introduce excess noise. It has also been assumed that avalanche multiplication has a build-up time shorter than the discussed inverse frequencies.

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Charge Analysis of Transistor Operation*

Beaufoy and Sparkes[1] have pointed out the usefulness of the charge concept in the analysis of transistor operation. One of the principle virtues of this method is that the time-dependent behavior of the transistor can be calculated from a knowledge of the dc properties of the device. In this note, we give a more general derivation of the basic equation used in charge analysis.

Consider a neutral region where n is the density of excess carriers of either sign in that region. Continuity requires

$$-\nabla\cdot J_n = \frac{n}{\tau} + \frac{\partial n}{\partial t} \quad (1)$$

where J_n is the particle current density and τ^{-1} is the recombination rate. Integrating (1) over the volume of the region, and assuming τ is constant in the region, we have

$$-\int \nabla\cdot J_n dv = \frac{N}{\tau} + \frac{\partial N}{\partial t} \quad (2)$$

where $N=\int n\, dv$ is the total number of excess carriers of a given sign in the region. By Gauss' theorem we have

$$\Delta I = \frac{N}{\tau} + \frac{\partial N}{\partial t} \quad (3)$$

where ΔI is the net particle current of a given type into the region. Multiplying through by q, the electronic charge, we finally have

$$q\Delta I = \frac{Q}{\tau} + \frac{\partial Q}{\partial t} \quad (4)$$

where $Q=qN$ is the total excess charge of either type in the region. Eq. (4) is the basic equation used in charge analysis. It is dependent only on the recombination model used and is independent of *any* of the other details of the region such as geometry, aiding or retarding fields, conductivity modulation, etc. Since the region is neutral, we may consider either majority or minority carrier flow at our convenience.

Under dc conditions, the charge in the base is given by

$$\frac{Q}{\tau} = \frac{1-\beta}{\beta} I_c = \gamma(1-\beta)I_e = \frac{\gamma(1-\beta)}{1-\alpha} I_B$$

where β is the base transport factor and γ the emitter efficiency. Defining the transit time[2] as the ratio of base charge to collector current, we have

$$\tau_t = \frac{(1-\beta)\tau}{\beta}.$$

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* Received by the IRE, October 21, 1959.

[1] R. Beaufoy and J. J. Sparkes, "The junction transistor as a charge-controlled device." *ATE J.*, vol. 13, pp. 3–20, October, 1957; also in PROC. IRE, vol. 45, 1740–42, December, 1957. For a discussion of charge control in various devices, see E. O. Johnson and A. Rose. "Simple general analysis of amplifier devices with emitter, control, and collector junctions," PROC. IRE, vol. 47, pp. 407–418; March, 1959.

[2] L. J. Varnerin, "Stored charge method of transistor base transit analysis" PROC. IRE, vol. 47, pp. 523–527; April, 1959.

As an example of the charge method of analysis, we calculate the transient response of a grounded emitter transistor to a step in base current. For simplicity, we neglect the charging of the collector capacitance. We then have

$$q\Delta I = I_B - (1-\gamma)I_e = \gamma I_B - (1-\gamma)I_c$$
$$= \frac{Q}{\tau} + \frac{\partial Q}{\partial t}. \quad (5)$$

At dc, $Q=\tau_t I_c$. We assume that $Q(t)=\tau_t I_c(t)$ at all times; *i.e.*, the collector current is proportional to the total charge in the base and is not dependent upon its distribution.

Then (5) becomes

$$\left(\frac{\alpha}{1-\alpha}\right) I_B = I_c + \frac{1}{\omega}\frac{\partial I_c}{\partial t} \quad (6)$$

where

$$\omega = \frac{1-\alpha}{(1-\beta)\tau} = \frac{1-\alpha}{\beta\tau_t}.$$

For $I_c(o)=0$, we have

$$I_c(t) = \left(\frac{\alpha}{1-\alpha}\right) I_B(1-e^{-\omega t}).$$

This agrees with the usual expression where the delay time, t^* has been neglected. By this treatment, however, we see that reducing the emitter efficiency is equivalent to a feedback that reduces the gain, but increases the frequency response, of a grounded emitter transistor.

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Determination of the Orbit of an Artificial Satellite*

Two recent letters have considered the determination of the orbit of an artificial satellite by means of multi-station Doppler tracking systems. In the first,[1] a system was indicated which was independent of the initial ranges, and could therefore be utilized to acquire as well as track vehicles in space, without previous position information. In the second,[2] it was pointed out that such a system would be open and require iteration, unless one relation in addition to the Doppler equations was obtained. This follows immediately from the fundamental relations for n stations and m successive time intervals:

$$\Delta R_{ij} = R_{i1} - R_{ij} \quad i = 1, \cdots, n \quad (1)$$
$$j = 1, \cdots, m$$

where the R_{ij} are the slant ranges, the ΔR_{ij} are the range increments, obtained from the Doppler data, and $R_{i1}=R_i$ are the initial ranges. Eq. (1) will result in $n-1$ equations in n unknowns. This clearly shows the need for an outside condition on the ranges.

As observed by Carrara, Checcacci and Ronchi, any of the R_{i1} may be expressed in terms of the remaining initial ranges; thus, one initial range in (1) may be expressed as a function of the other $n-1$ initial ranges. Recent work in this laboratory,[3,4] based upon these observations, has resulted in a solution of (1) for the ranges. The result derives from the existence of a geometrical relation among ranges to four stations in an arbitrary configuration in a common ground plane from a point in space.

The work may be outlined as follows. Writing the equations for four stations arranged in a cross as

$$(x_j \pm a)^2 + y_j^2 + z_j^2 = R^2_{ij}, \; i = 1, 2 \quad (2)$$
$$j = 1, 2, 3, \cdots$$

$$x_j^2 + (y_j \pm a)^2 + z_j^2 = R^2_{ij}, \; i = 3, 4 \quad (3)$$
$$j = 1, 2, 3, \cdots$$

and combining (2) and (3), one obtains the geometrical property

$$R_{1j}^2 + R_{2j}^2 = R_{3j}^2 + R_{4j}^2. \quad (4)$$

Since this is a purely geometrical relation, it holds for any j. As the difference of any two successive time-dependent values of any R_{ij} is equal to a range increment, proportional to the Doppler data obtained during the interval, one can write, for four successive observations:

$$(R_1 + \Delta R_{1j})^2 + (R_2 + \Delta R_{2j})^2 =$$
$$(R_3 + \Delta R_{3j})^2 + (R_4 + \Delta R_{4j})^2$$
$$j = 1, 2, 3, 4. \quad (5)$$

These may be linearized by use of (4); the resulting equation may be solved for the R_i and, with these, the succeeding ranges are obtained from (1). For a particular j any three of the four R_{ij} will serve to find the coordinates, x_j, y_j, z_j from (2) and (3). The Jacobian of this transformation yields a criterion for choosing the three R's resulting in the most accurate values of x_1, y_1, z_1.

These results may be generalized to include an arbitrary configuration of stations in the ground plane.

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* Received by the IRE, November 5, 1959.

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[2] J. T. Anderson, "Determination of the Orbit of an Artificial Satellite," Proc. IRE, vol. 47, pp. 1658–1659; September, 1959.

[3] P. T. McCormick, "Tracking of a CW Transmitter-Carrying Vehicle with a Four-Station System by Utilizing the Doppler Effect," Philco WDL Memo; August, 1959.

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Radiation Damage and Transistor Life in Satellites*

Evidence in support of a region of intense nuclear radiation surrounding the earth became indisputable with the flight of the satellite 1958ϵ [1] on July 26, 1958, in the wake of 1958α and γ. Several theories of the origin and nature of the radiation were proposed, each of which would partially remove the ambiguity of the particles comprising the radiation and allow an estimate of radiation damage. Equal *a priori* weight was attached to theories suggesting protons [2] and electrons [3]. Further uncertainty arose when the results [4] of the Pioneer I flight (October 1958) were compared with previous results. The interpretational difficulties imposed by this mass of data were resolved for altitudes below 1200 km by the experiment reported by Freden and White [5]. In this experiment a stack of nuclear emulsions was carried to an altitude of 1230 km and recovered after the flight. Analysis of the tracks in the emulsions verified that protons comprise the inner charged particle radiation band and permitted an accurate estimate of the energy spectrum.

The Freden and White proton-energy spectrum has been employed as the basis for estimating the rate of atomic displacements produced in silicon and germanium transistors during exposure to the inner charged particle belt. Previous estimates [6], by failing to account properly for the importance of high energy protons in producing displacements, have yielded displacement production rates far lower than those obtained here. The present estimates are also in better agreement with the limited experimental data for radiation damage produced by high energy protons.

In calculations of radiation damage to semiconductors, *e.g.*, Si or Ge, the practice has been to consider atomic displacements only and to ignore all but the Rutherford-type energy losses of the incident particle and successive knock-on Si or Ge atoms. The effect of inelastic $(n, n'\gamma)$ nuclear encounters has usually been dismissed on the grounds that the cross section for these events is relatively small at the energies usually considered and, moreover, is assumed to have a $1/E$ dependence, presumably well above their threshold.

Above 20 mev, however, nonelastic encounters (*e.g.*, neutron and charged particle emission) become of increasing importance [7]. Above 100 mev (which embraces almost 50 per cent of the radiation belt protons), nuclear disintegrations begin to dominate in importance over all other interactions, with increasing production of "stars" or small-scale spallation effects. Monte Carlo calculations based on high-energy "evaporation" models [8]–[17] and the phenomenological data obtained, mainly from analyses of nuclear emulsion events, indicate the importance of these phenomena in producing atomic displacements. These displacements occur not because of the knock-ons produced by incident protons,

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* Received by the IRE, September 8, 1959.

but by virtue of the nuclear disintegrations in which they give rise to neutrons, protons, alphas, etc., of just about the right energy (5–20 mev) to produce a large number of atomic displacements by Rutherford collision within a thin Si or Ge wafer.

This is of importance, *a fortiori*, when it is contrasted with the small energy loss of an incident proton of 100 mev and more when it passes through the material in which the possibility of nuclear disintegrations has not been included. Smoluchowski reports on the results of irradiation of alkali halides with 100–400 mev protons [18] and concludes that at high energy the radiation effects caused by the secondary nucleons originating in the "inelastic" collisions are *at least* as important, if not more so, than those produced directly by elastic collisions of the incident protons.

For the reasons given, we have divided the problem into two parts:

1) $E<100$ mev,
2) $E>100$ mev.

1) $E<100$ mev

Each primary knock-on energy E produces $E_p/2E_d$ displacements [19], where E_d is the displacement energy which has been variously estimated as between 12–30 ev for Si and Ge [19], [20]. In calculating the total number of atomic displacements per target atom, the contributions of the primaries and successive knock-ons of lower order are summed separately; *i.e.*, N_d = primary displacements + progeny displacements. These relations are found [19], [20] to be:

$$N_d = \int_{E_d}^{E_{\max}} N_p dE_p + \int_{2E_d}^{E_{\max}} N_p \frac{E_p}{2E_d} dE_p$$

$$= \frac{CN_i}{E_iE_d}\left(1 + \frac{1}{2}\ln\frac{E_{\max}}{2E_d}\right);$$

where

$$C = \pi\left(\frac{Z_1Z_2e^2}{A_1 + A_2}\right)^2 A_1A_2$$

N_i = Incident flux,
E_i = Energy of incident particle,
N_d = Rate of atomic displacement.

The results of our calculations at an altitude of 1200 km appear in Table I. The estimates are conservative in view of the $1/E_i$ dependence assumed.

2) $E>100$ mev

The number of defects/cm³ produced by high-energy protons cannot be determined accurately because the exact mechanism of defect production by the nuclear fragments is not sufficiently well known to permit quantitative evaluation. We rely for the present, therefore, on experimental results obtained with NaCl and KCl [18], [22] which indicate that 1000 to 5000 defects per cm³ are formed by each incident proton per cm² above 100 mev. At an altitude of 1200 km, an omnidirectional flux of 560 protons/cm²/sec above 100 mev produces about 2–4×10⁶ defects/cm³/sec. Evidently, far from ignorable [6], each proton above 100 mev will form 1–5 times as many defects per cm³ as the lower energy (1–20 mev) particles usually considered important. Since the nonelastic collision cross section for "star" reactions varies approximately as $A^{2/3}$, the defect density from the high energy protons in Ge will be about twice that in Si. This is probably an underestimate since the fragments in the case of Ge will consist on the average of a higher mass with resultant increased ability to produce defects. Corresponding to the tabulated results for the lower energy proton component, the results for the protons above 100 mev at 1200 km are shown in Table II. The total damage rates, assuming a 12½ ev displacement energy are shown in Table III.

TABLE I

	N_d/proton/cm³		N_d/cm³-sec	
	E_d = 25 ev	E_d = 12½ ev	E_d = 25 ev	E_d = 12½ ev
Silicon	600	1200	.45×10⁶	.92×10⁶
Germanium	1000	2200	.75×10⁶	1.7 ×10⁶

TABLE II

	N_d/cm³-sec		Nd/proton/cm³	
	E_i = 25 ev	E_i = 12½ ev	E_i = 25 ev	E_i = 12½ ev
Silicon	0.85×10⁶	1.7×10⁶	1500	3000
Germanium	1.7 ×10⁶	3.4×10⁶	3000	6000

TABLE III

	N_d/proton/cm³	N_d/cm³-sec (1200 km)
Silicon	2000	2.6×10⁶
Germanium	4000	5.1×10⁶

In order to estimate transistor lifetime, a criterion of damage must be decided upon. There are a number of possibilities. Without discussing the relative merits of each, it seems somewhat more desirable to draw upon the vast quantity of data from reactor irradiation of semiconductors, because the local defect distribution produced by protons bears a closer similitude to fast neutron damage [23], and because of the availability of statistical data [24] for a large number of transistor types. Considerable variation of radiation sensitivity is found between different transistors which requires a certain arbitrariness in selecting a damage criterion, The data suggests setting neutron doses of $10^{12}n$/cm² for silicon devices and $10^{13}n$/cm² for germanium transistors. However, a critical radiation dose for a particular device may vary considerably from the criteria which were selected. The resulting defect densities using the theory described by Dienes and Vineyard [25] are:

Si, 5×10¹⁴ displacements/cm³;
Ge, 3.8×10¹⁵ displacements/cm³.

These defect densities are produced at 1200 km altitude in 9.2×10⁷ seconds (1060 days) in silicon and in 3.8×10⁸ seconds (4060 days) in germanium.

Using the flux-altitude relation obtained by Van Allen [1] and assuming that the Freden and White energy spectrum is independent of altitude, a curve of transistor lifetime vs equatorial (±25°) altitude can be constructed (see Fig. 1). The curves shown in Fig. 1 are necessarily limited to the inner radiation belt, for no accurate particle energy data for the outer belt have been obtained and are reliable only up to 1350 miles (2200 km), the highest data reported by Van Allen from 1958ε. The curves have been extrapolated through the anticipated maximum of the inner belt but are not supported by direct experimental measurement as are lower altitude data.

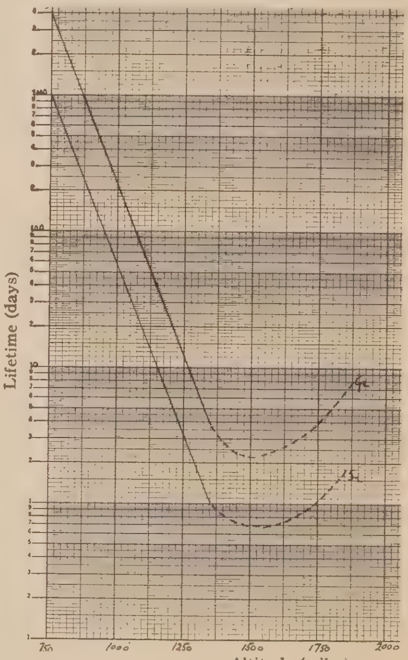

Fig. 1—Lifetime of semiconductors exposed in the inner equatorial (±25°) radiation belt as a function of altitude.

Clearly, semiconductor lifetime in satellites is an important consideration for altitudes in the 1500 mile (2500 km) range. If a one-year semiconductor life is desired, equatorial altitudes between 1000 and 2200 miles are unsuitable. Of course, many orbits will not be restricted solely to equatorial latitudes, nor is it reasonable to expect circular orbits. These considerations tend to increase the lifetime in orbit.

Frequently it is desirable to operate in a high radiation area and protect equipment from shielding. We have not considered the shielding question in detail, but preliminary considerations seem to rule out protection by shielding for present payloads. The range of a 100-mev proton is about 1.5 cm in Pb; since about half of the damage is produced by the protons above 100 mev, it is clear that several cm of Pb will be required to increase semiconductor lifetime significantly. Furthermore, since the total cross section we are discussing for nucleon-nucleon encounters is a few barns in usual shield materials and these cascade products are forward scattered in addition to other less preferentially radiated products, it appears that the use of thin shields may lead to an increase in damaging radiation. This shielding paradox is receiving further attention, particularly with respect to various shield materials and thicknesses.

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Increasing the Dynamic Tracking Range of a Phase-Locked Loop*

The transient response and effective noise bandwidth of a phase-locked loop are related to the dynamic tracking range. However, the latter often can be adjusted without adversely affecting the first two. "Dynamic tracking range" refers to the range in frequency over which a phase-locked loop will track a signal of slowly-varying frequency (*i.e.*, Doppler shift) once the loop has locked on.

Consider the loop of Fig. 1. Fig. 1(a) shows a typical configuration, and Fig. 1(b) is the linear equivalent after Jaffe and Rechtin.[1] The low-frequency component out of the multiplier due to the signal is

$$K_m E_s E_0 \sin(\theta_1 - \theta_2)$$

where K_m is a constant associated with the multiplier. Amplifier K_1 represents the change in frequency vs voltage (cps/volt). Let the filter have unity dc gain. Since the maximum output from the multiplier is $\pm K_m E_s E_0$, the maximum frequency change of the (dynamic tracking range) VCO for a signal of slowly-varying frequency (almost dc from the multiplier) is:

$$\Delta f_m = \pm K_m E_s E_0 A K_1. \qquad (1)$$

The generalized feedback equation for a negative sign on the summer is:

$$\frac{C(S)}{R(S)} = \frac{K_a F(S)}{1 + K_a K_b F(S) H(S)} \qquad (2)$$

where $K_a F(S)$ is the transfer function in the feed-forward path and $K_b H(S)$ is the transfer function in the feed-backward path. Writing $F(S)$ and $H(S)$ in terms of their poles and zeros shows that the poles of $H(S)$ and the zeros of $F(S)$ are the zeros of (2). The poles of $C(S)/R(S)$ may be found by solving for the roots of the equation:[2]

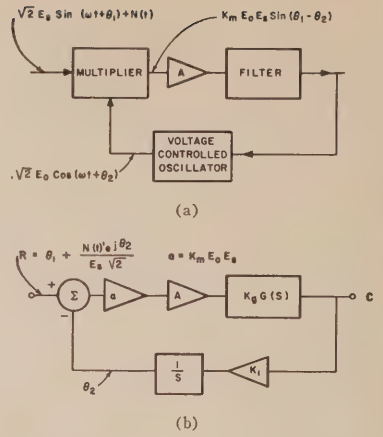
$\sqrt{2}$ E$_s$ Sin (ωt+θ_1)+N(t)
K$_m$ E$_0$ E$_s$ Sin (θ_1 - θ_2)
MULTIPLIER
A
FILTER
VOLTAGE CONTROLLED OSCILLATOR
$\sqrt{2}$ E$_0$ Cos (ωt+θ_2)
(a)
R = θ_1 + $\frac{N(t)' e^{j\theta_2}}{E_s \sqrt{2}}$
a = K$_m$ E$_0$ E$_s$
+
Σ
−
a
A
K$_g$ G (S)
C
1/S
K$_1$
θ_2
(b)

Fig. 1—(a) A phase-locked loop. (b) The linear equivalent $N(t)'$ is $N(t)$ translated from ω to a center frequency of zero.

$$K_a K_b H(S) F(S) = -1. \qquad (3)$$

For the loop of Fig. 1(b), (3) is

$$A K_m E_0 E_s K_g K_1 \frac{G(S)}{S} = -1 \qquad (4)$$

or

$$\left| \frac{G(S)}{S} \right|_{P_0} = \frac{1}{A K_m E_0 E_s K_g K_1}, \qquad (5)$$

and

$$\angle \frac{G(S)}{S} = 180° \qquad (6)$$

where

$$F(S) = G(S)$$

and

$$H(S) = \frac{1}{S}.$$

Then the closed loop will have one zero at the origin (due to $1/S$) and other zeros due to the zeros of $G(S)$.

If $K_g G(S)$ has unity dc gain,

$$\lim_{S \to 0} K_g \frac{\prod_j (S + a_j)}{\prod_i (S + b_i)} = \lim_{S \to 0} K_g G(S) = 1. \qquad (7)$$

Then

$$K_g = \frac{\prod_i b_i}{\prod_j a_j}. \qquad (8)$$

Assume that the transient response requires poles of $C(S)/R(S)$ at P_0 and P_0^* of Fig. 2. Eq. (6) is satisfied when

$$\sum_j \theta_j - \sum_{i=2}^{n} \phi_i - \phi_1 = \pi; \qquad (9)$$

n is the number of poles in $G(S)$, θ_j is the angle from the jth zero to P_0, and ϕ_i is the angle from the ith pole. The graphical

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* Received by the IRE, October 9, 1959.

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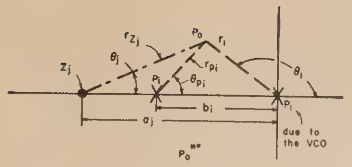

Fig. 2—S-plane plot Z_j is the jth zero of $G(S)$; P_i is the ith pole of $G(S)/S$.

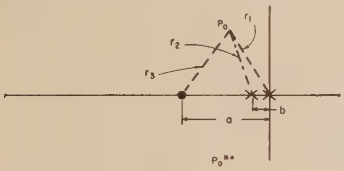

Fig. 3—S-plane plot when $KgG(S)$ is the network of Fig. 4.

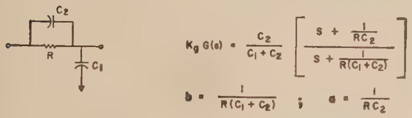
C_2
R
C_1
$K_g G(s) = \frac{C_2}{C_1+C_2}\left[\frac{S+\frac{1}{RC_2}}{S+\frac{1}{R(C_1+C_2)}}\right]$
$b = \frac{1}{R(C_1+C_2)}$; $a = \frac{1}{RC_2}$

Fig. 4—A typical $KgG(S)$.

method of finding the absolute magnitude gives[3]

$$\left|\frac{G(S)}{S}\right|_{P_0} = \frac{\prod_j r_{z_j}}{r_1 \prod_{i=2}^{n} r_{P_i}}. \tag{10}$$

Using (1), (8), and (10), (5) may be written:

$$AK_mE_0E_sK_1 = r_1 \frac{\prod_{i=2}^{n} \frac{r_{pi}}{b_i}}{\prod_j \frac{r_{zj}}{a_j}} = |\Delta f_m|. \tag{11}$$

If $G(S)$ is the simple lag network shown in Figs. 3 and 4, (11) is

$$|\Delta f_m| = r_1 \frac{\frac{r_2}{b}}{\frac{r_3}{a}}, \tag{12}$$

where a and b are as defined in Figs. 3 and 4.

If $b \ll a$, it is clearly seen that as b decreases, $|\Delta f_m|$ increases, allowing more or less independent adjustment. In theory, $|\Delta f_m|$ can be made arbitrarily large by making b arbitrarily small. Notice that the dynamic tracking range is directly proportional to r_1 which is a measure of the closed-loop bandwidth. This is in agreement with the observation that $|\Delta f_m|$ is often approximately the same as the loop bandwidth. A more complex filter may be required to shape the transient response, and for a multisection filter, (11) will give the value of $|\Delta f_m|$. With a slowly-varying signal frequency, these calculations should be very close to the value obtained in practice.

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Combined AM and PM for a One-Sided Spectrum*

Chakrabarti[1] declares that he has not seen any report about the method of obtaining single-sideband modulation by simultaneous amplitude and phase modulation. The late Professor Barkhausen[2] pointed out the identity of single-sideband amplitude modulation with simultaneous amplitude and phase modulation, illustrating the theory with diagrams. He also discussed the matter in classroom lectures.

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* Received by the IRE, October 13, 1959.

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On the Large-Signal Aspect of the Broadband Multicavity Klystron Problem—Theory and Experiment*

In previous work by the author[1] and others,[2–5] methods have been devised (and applied to some problems) to calculate the performance of multicavity klystrons, namely, their broadband response and other characteristics under small signal conditions, including the effects of space-charge.

The present communication deals with an extension of the previous procedure which will be applicable at large signal levels. Although either an analog or a digital computer can be employed, we shall concern ourselves only with an analog solution and experimental verification in the case of a specific tube.

With the aid of the assumptions already indicated[6] one writes for a drift region

$$i_b = [i_a \cos\theta_{ab} + v_a jg \sin\theta_{ab}]e^{-i\psi}ab,$$
$$v_b = [v_a \cos\theta_{ab} + i_a jg^{-1} \sin\theta_{ab}]e^{-i\psi}ab \tag{1}$$

and, at a resonator gap, we have

$$i_b' = i_a' e^{-i\psi}g,$$

$$v_b' = \left[M^2Z(\omega)\,\frac{\eta}{u_0}\,i_a' + v_a'\right]e^{-i\psi}g \tag{2}$$

where the quantities i (i and i') and v (v and v') represent the ac current and ac velocity of the beam, respectively. Subscripts a and b denote the earlier and later planes transverse to the electron beam; *i.e.*, the beam is traveling from a to b.

$$g = -\frac{\omega I}{\omega_q u_0}.$$

I is the dc current, ω the operating angular frequency, u_0 the dc velocity of the beam and ω_q is the reduced plasma angular frequency.

$$\theta_{ab} = \frac{\omega_q d_{ab}}{u_0}.$$

d_{ab} = distance between planes a and b

$$\psi_{ab} = \frac{\omega d_{ab}}{u_0}.$$

M is the beam coupling coefficient, $Z(\omega)$ is the shunt impedance across the gap, and $\eta = e/m$ (charge to mass ratio) for an electron.

Eqs. (1) and (2) completely describe the behavior of any arrangement of cavities and drift spaces under the assumption of small signals. By a repeated application of (1) and (2), then, we can determine gain, power, bandwidth, etc., under small signal conditions.

Suppose, then, that an n-cavity klystron is considered. Let the ac voltage across the mth cavity be V_m; then

$$V_m = M_m Z_m i_m \tag{3}$$

where M_m, Z_m, and i_m represent the beam coupling coefficient, shunt impedance and the entering ac current at the mth gap.

One can also write

$$i_m = -j \sum_{k=1}^{m-1} \alpha_{km} V_k, \tag{4}$$

but for a phase factor, where,

$$\alpha_{km} = -M_k g \frac{\eta}{u_0} \sin\theta_{km} = M_k Y_0 \sin\theta_{km},$$

for instance,

$$\theta_{km} = \omega_q \frac{d_{km}}{u_0},$$

$$Y_0 = -\frac{g\eta}{u_0},$$

d_{km} = axial distance between cavities k and m. From (3) and (4) the ac voltage across cavity $n-1$ is

$$V_{n-1} = \left(\sum_{k=1}^{n-2} F_{k,n-1} V_k\right) e^{-i\psi}1, n-1,$$

where

$$F_{k,n-1} = -jM_{n-1}Z_{n-1}\alpha_{k,n-1}$$

$$\psi_{1,n-1} = \frac{\omega}{u_0} d_{1,n-1}. \tag{5}$$

If V_1 is the ac voltage exciting the input cavity and V_{n-1} is the ac voltage across the penultimate cavity, the following expressions for voltage gain can be written:

$$\frac{V_{n-1}}{V_1} = e^{-i\psi}1, n-1\,[F_{1,n-1} + F_{2,n-1}F_{12} + F_{3,n-1}(F_{23}F_{12} + F_{13}) + \cdots]. \tag{6}$$

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* Received by the IRE, September 25, 1959.

[1] S. V. Yadavalli, "Application of the potential analog in multicavity klystron design and operation," Proc. IRE, vol. 45, pp. 1286–1287; September, 1957.

[2] K. H. Kreuchen, B. A. Auld, and N. E. Dixon, "A study of the broadband frequency response of the multicavity klystron amplifier," *J. Electronics*, vol. 2, p. 529; May, 1957.

[3] W. L. Beaver, R. L. Jepsen, and R. L. Walter, "Wideband klystron amplifier," 1957 IRE Wescon Convention Record, pt. 3, pp. 111–113.

[4] L. D. Smullin and A. Bers, "Stagger tuned multicavity klystrons," presented at the Conference on Electron Tube Research, Berkeley, Calif.; June, 1957.

[5] H. J. Curnow, "Factors influencing the design of multicavity, klystrons," *SERL Tech. J.*, vol. 8, p. 42; January, 1958.

[6] S. V. Yadavalli, *op. cit.*; these assumptions are inherent to the Llewellyn-Peterson equations in an appropriate form.

The large signal aspect is included as follows. Although the effects of large signals should be included even at an earlier stage in the solution of the problem, we assume here that small signal theory holds up to the computation of i_{n-1} (the current exciting the penultimate cavity). For the computation of the ac current exciting the nth (output) gap, the following approximation[7] is made

$$i_n = 2IJ_1(X_{n,n-1}), \qquad (7)$$

where J_1 is a Bessel function of the first kind of order one

$$X_{n,n-1} = \left(M_{n-1}\frac{\omega\eta V_{n-1}}{\omega_q u_0^2}\sin\theta_{n,n-1}\right). \qquad (8)$$

From a knowledge of i_n, (R/Q), and Q_n, it is not a difficult matter to calculate the power output and efficiency of the tube, since

$$V_n = M_n Z_n i_n,$$

$$P_{\text{out}} = \eta_c P_n = \frac{1}{2}\frac{|V_n|^2}{Z_n}\cdot\eta_c,$$

η_c being the output circuit efficiency. The electronic efficiency of the tube is $P_{\text{out}}/V_0 I$ where V_0 is the dc beam voltage.

The analogy with IF amplifier design has been discussed previously and will not be repeated here. Some details about the computer method of solution have been given elsewhere in literature.[8]

Employing the above model, computations have been made on an analog computer[9] to obtain the optimum bandwidth with a five-cavity X-band klystron. Fig. 1 shows the theoretical output power and the experimental verification of the same. The theoretical 3-db bandwidth is 59.0 mc, as compared with the experimental value of 57.0 mc. As can be seen, the agreement between theory and experiment is very good.

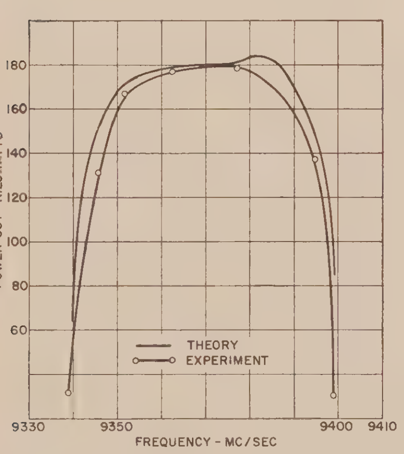

Fig. 1—Performance characteristics of five cavity X-band klystron (theory and experiment).

The author would like to thank John H. Trumpler of the General Electric Microwave Lab., Palo Alto, Calif. for taking the experimental data.

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[7] This approximation appears to be valid and quite adequate at the present time.

[8] D. M. Byck and A. Norris, "On the solution of some microwave problems by an analog computer," 1958 IRE Wescon Convention Record, pt. 1, pp. 70–87.

[9] These computations have been made by the EAI computation center, Los Angeles, Calif.

High Q Inductance Simulation*

An improvement which can be made to the pentode simulation of reactance,[1] particularly inductive reactance, is the elimination of the resistance component. This gives the simulated inductance an infinite Q. An advantage of such a simulator besides the high Q is that it has a smaller volume and lighter weight than an equivalent wire-wound iron-cored inductor. Circuits for simulation of components have been investigated by several authors and an extensive bibliography is contained in a recent survey by Cooperman and Franklin.[2]

The resistance component results from the plate resistance r_p and the resistance present in the plate load. This can be seen by referring to the equivalent current generator circuit of Fig. 1. The parallel combination of r_p and plate load resistance component is represented by R_{eq}. The choke prevents the ac input from being shorted out by the plate voltage power supply.

The input current can be expressed as follows:

$$i = i_p + e\left(\frac{1}{R_{\text{eq}}} + \frac{1}{sL} + sC\right). \qquad (1)$$

The turn-to-turn capacitance is represented by C. Tube interelectrode capacitances are neglected as is the large input blocking capacitor C_b.

To nullify any effect of the plate load on the input terminals, one component of the pentode excitation voltage e_g causes a cancellation current to flow. The other component provides excitation voltage of the correct phase so as to make the pentode draw reactive current from the input.

The pentode current can be represented by two components as follows:

$$i_p = g_m e_g = g_m e_{g1} + g_m e_{g2}. \qquad (2)$$

Substituting (2) into (1),

$$i = g_m e_{g1} + g_m e_{g2} + e\left(\frac{1}{R_{\text{eq}}} + \frac{1}{sL} + sC\right), \qquad (3)$$

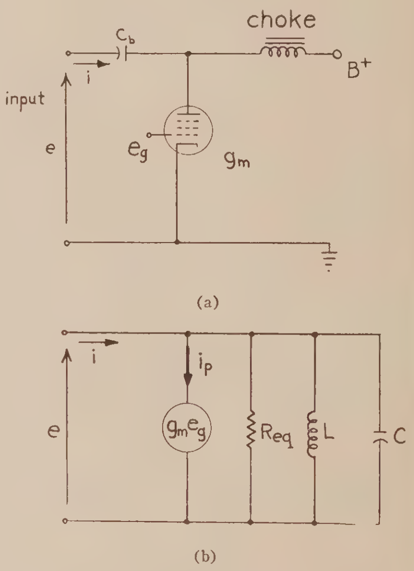
it is clear that to nullify the right hand term in (3), either one of the two components of i_p must be its negative; such as,

$$-g_m e_{g1} = e\left(\frac{1}{R_{\text{eq}}} + \frac{1}{sL} + sC\right).$$

Upon rearranging, this becomes:

$$\frac{e_{g1}}{e} = -\frac{1}{g_m}\left(\frac{1}{R_{\text{eq}}} + \frac{1}{sL} + sC\right). \qquad (4)$$

One method of providing this transfer function is through use of the circuit of Fig. 2.[3]



(a)

(b)

Fig. 1—Reactance tube circuit and its current generator equivalent network.

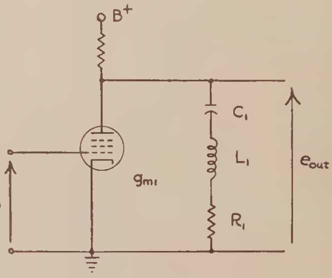


Fig. 2—Network to realize nullifying transfer function.

Here a series R-L-C circuit loads the plate of a pentode and provides a network transfer function of:

$$\frac{e_{\text{out}}}{e_{\text{in}}} = \frac{-g_{m1}}{\dfrac{1}{R_n} + \dfrac{1}{\dfrac{1}{sC_1} + sL_1 + R_1}}. \qquad (5)$$

The parallel combination of plate resistance and plate load resistance is represented by R_n.

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* Received by the IRE, September 14, 1959.

[1] War Training Staff of the Cruft Lab., Harvard University, Cambridge, Mass., "Electronic Circuits and Tubes," McGraw-Hill Book Co., Inc., New York, N. Y., p. 667; 1947.

[2] J. I. Cooperman and P. J. Franklin, "Circuit techniques to eliminate large volume components, a literature survey," *Electronic Design*, vol. 7, no. 6, pp. 52–61; March, 1959.

[3] J. G. Truxal, "Control System Synthesis," McGraw-Hill Book Co., Inc., New York, N. Y., p. 187; 1955.

If

$$R_n \gg \left| R_1 + sL_1 + \frac{1}{sC_1} \right|$$

for frequencies of interest, (5) becomes

$$\frac{e_{\text{out}}}{e_{\text{in}}} \doteq - g_{m1} \left(R_1 + sL_1 + \frac{1}{sC_1} \right).$$

This expression is equivalent to (4) since the following dimensionless identities hold:

$$g_{m1}R_1 \equiv \frac{1}{g_m R_{\text{eq}}},$$

$$g_{m1}sL_1 \equiv \frac{sC}{g_m},$$

$$\frac{g_{m1}}{sC_1} \equiv \frac{1}{g_m sL}.$$

Upon connecting the network of Fig. 2, to provide excitation to the pentode, the input current to the simulator becomes

$$i = g_m e_{g2}.$$

In order that the input impedance be of the form sL_{in}, e_{g2} must lag e by 90° since

$$e_{g2} = \frac{e}{g_m s L_{\text{in}}}.$$

One method of obtaining e_{g2} from e is by use of an isolation amplifier and pentode loaded with a capacitor.

An improvement in the linearity of the simulator is obtained by using negative current feedback. The input current is sensed and the voltage amplified and fed back to the simulator pentode control grid. Second harmonic current is reduced substantially in this way.

The complete circuit is shown in Fig. 3.

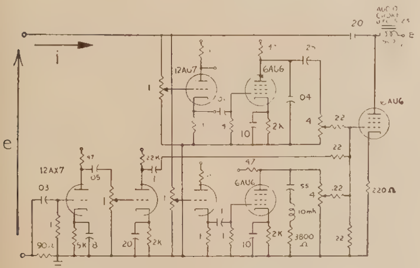

Fig. 3—Complete inductance simulator circuit.

Other kinds of two-terminal simulations are possible with this kind of circuit because of the flexibility allowed by having the input impedance a function of e_{g2} alone. One possibility is a negative inductance. It can be obtained simply by reversing the terminals at the output of the isolation amplifier in Fig. 3. Another is obtained when e_{g2} is obtained through two pentode-capacitor circuits in cascade. The input impedance then becomes proportional to $(sL)^2$.

The positive inductance simulator of Fig. 3 has a frequency range of 60 to 2000 cps, with an equivalent magnitude range of 28 to 2800 henries.

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HF Noise Radiators in Ground Flashes of Tropical Lightning*

Previous analyses of this subject[1,2,3] ignore ground flashes because 1) they constitute less than 10 per cent of all discharges in the tropics,[4] and 2) the noise power involved at HF is not significantly different from that of cloud discharges. This letter gives the results of an analysis[5] for substantiating 2). It assumes information contained in Schonland[6] and Aiya.[1–7]

Results

A tropical ground flash lasts 0.2 second. It has four major discharges. Each such discharge consists of a leader stroke, a return stroke and M-components or M-type of discharge (it is the author's view that M-components are, in several respects, similar to the leader discharge with all its possible variations). The approximate time interval between successive major discharges, as measured between commencements of return strokes, is 0.04 second. A flash commences with a B field change which has significant pulsations at the beginning. In between the major discharges there is the J field change and, after the last major discharge, there is the F field change. The long-duration B, J and F field changes exhibit fluctuations which result in noise radiation of low power.

A typical tropical ground flash as an HF noise radiator is described in Table I. Type classification is based on the rms noise field strength corresponding to the average power received from an emission. The maximum or peak value of this quantity, A, arises from stage I of the leader discharge and can be calculated from (7) in Aiya.[2]

TABLE I

HF Noise Sources in Tropical Ground Flashes

Type number	rms field strength	Probable source of emission in the flash	Duration in Milli-seconds	Number of times it occurs in each flash	Total maximum duration of type in each flash	Remarks
I	$\frac{A}{16}$	1) Fluctuation of the B field change. 2) Fluctuation in the J field change. 3) Fluctuation in the F field change.	30 30 30	1 3 1	150	
II	$\frac{A}{8}$	1) Initial pulsive part of B field change. 2) M-components following each return stroke.	5 5	1 4	25	
III	$\frac{A}{4}$	Stage III or α portion of the first leader stroke	11	1	11	Of much shorter duration when height of cloud base is low
IV	A	Stage I of all leaders	1	4	4	
V	A	Stage II of first leader	2	1	2	Part or whole of it may not exist
VI	—	Return stroke. Behaves as a long vertical grounded aerial for HF with main lobe in polar diagram practically vertical and minor subsidiary lobes	1–2	4	8	Prominent reflected pulses from the ionosphere possible at short distances
VII	—	Stages II and III of second, third and fourth leaders or dart leaders	1	3	3	Radiation pattern similar to return stroke but with lower amplitudes

Departures from the description in Table I are to be expected because, even in the tropics, ground flashes show a greater variety than cloud discharges. This is probably due to 1) wide variations in the height of the cloud base above ground (it being very low in India after the regular monsoon has set in); 2) the general topography of the place, such as hills, high structures, etc., and electrical characteristics of the ground. When the height of the cloud base is low, some flashes may take the form of a continuous discharge to ground on which are superposed a very large number of M-components, and some may become one stroke flashes with a continuous discharge as described for the rest of the flash, and so on.

Noise Records

Recording of radiations from one complete cloud discharge requires very careful design of experiments, etc. It is not so for ground flashes because there is almost continuous radiation throughout the flash. Even when it is not visible, a ground flash is easier to identify as it radiates VLF noise also; however, precautions have to be taken in interpreting the records. First, there is the integrating effect of the recording gear be-

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* Received by the IRE, October 7, 1959.

[1] S. V. C. Aiya, "Noise power radiated by tropical thunderstorms," Proc. IRE, vol. 43, pp. 966–974; August, 1955.

[2] S. V. C. Aiya, "Atmospheric noise interference to short wave broadcasting," Proc. IRE, vol. 46, pp. 580–589; March, 1958.

[3] S. V. C. Aiya, "Average power of impulsive atmospheric radio noise," Proc. IRE, vol. 47, p. 92; January, 1959.

[4] S. V. C. Aiya, "Atmospheric noise interference to medium wave broadcasting," IRE Proc., vol. 46, pp. 1502–1509; August, 1958.

[5] S. V. C. Aiya, "Atmospheric noise radiators," to be published.

[6] B. F. J. Schonland, "The lightning discharge," in "Handbuch der Physik," S. Flugge-Marburg, Ed., Springer-Verlag, Berlin, Germany, vol. 22, pp. 576–628; 1956.

[7] S. V. C. Aiya, C. G. Khot, K. R. Phadke and C. K. Sane," Tropical thunderstorms as noise radiators," *J. Sci. Ind. Res.* (India), vol. 14B, pp. 361–376; August, 1955.

cause of its time constants. Secondly, close distance records depend on the height of the cloud base above ground, as most of the emissions originate from inside the cloud.

Extraneous noises always affect the records. There is always the noise from distant thunderstorms and, perhaps, galactic noise as a background. There are additional complications at close distances; there can be electrostatic fields arising from various causes; and furthermore, pulses from the return strokes and dart leaders may be received after ionospheric reflection along with M-components or J or F field change fluctuations. (It is not impossible to get such reflected pulses even when they are ruled out by MUF considerations, one of the several reasons for this being the abnormal ionization associated with thunderstorms.) The contributions from such extraneous noises are small and do not significantly affect the peak amplitude A. But, in other cases, what is recorded is the resultant amplitude deduced by applying the method of Friis.[8]

Power Per Flash

The rms field strength B per flash can be calculated from Table I in terms of A as follows:

B for a ground flash

$$= \sqrt{\frac{6 \cdot A^2 + 11 \cdot \frac{A^2}{16} + 25 \cdot \frac{A^2}{64} + 150 \cdot \frac{A^2}{256}}{200}} \tag{1}$$

$$= (0.2) \cdot A. \tag{2}$$

B for a cloud discharge as calculated earlier[3] is

$$\sqrt{\frac{4}{200}} \cdot A = (0.14) \cdot A. \tag{3}$$

B for a ground flash is about 3 db higher but, in actual records, it may even appear to be as much as 10 db higher due to extraneous contributions, etc., discussed. We conclude, therefore, that the HF noise powers involved in ground and cloud discharges are not very significantly different. Interference calculations will probably require either A or the quasi peak value, as described in Fig. 3 of Aiya.[2] The present analysis indicates that neither of these two quantities would be seriously affected by the subsidiary radiations in a ground flash.

Temperate Region Records

Horner and Clarke[9] and Horner[10] have published photographs of noise bursts in England at 11 mc with a 300-cps bandwidth. The photographs, their statements, and the fact that they have recorded VLF noise also simultaneously in most cases, indicate that their records are for ground flashes. There does not appear to be any feature in the photographs which is not covered by the discussion in this letter. It is, however, not unlikely that there would be some differences in the nature of atmospherics radiated by sources located in tropical and temperate regions but it would be premature to draw conclusions on the point at present.

Horner and Clarke[9] have measured the peak amplitudes on their records for distances of storm d, varying from 1 to 18 km. This peak amplitude corresponds to A and it can be calculated from (7) in Aiya.[2] For a space wave at 11 mc with 300-cps bandwidth, we get

$$A = (2.40) \cdot \frac{\sin \theta}{r} \ \mu\text{V/m} \tag{4}$$

where, θ = angle the direction of radiation makes with the axis of the dipole and r = distance of the source in 10^6 meters.

Close-distance calculations require the height of the cloud base, h, which is not given and has, therefore, to be estimated. As measured by them, d is the hypotenuse of a right-angled triangle of which H, the mean height of the radiator, is only one side. Since d could even be 1 km, it follows that H must be less than 1 km. Assuming $h = 0.3$ km, a not uncommon value, there would be no stage II for the leaders and stage I of first leader would start from cloud base and extend to 1 km above, *i.e.*, $H = 0.8$ km. For stage I of second leader, $H = 0.8 + 0.7 = 1.5$ km, and so on. (It may be pointed out that other possible assumptions for values of h will not materially change the calculated values.) Values from (4) and the measured values of Horner and Clarke are given in Table II. In the tropics, it is expected that measured values on individual storms would lie within ±3 db of the calculated values from (4) in the majority of cases. Hence, the agreement in Table II for temperate regions should be considered very satisfactory.

TABLE II
CALCULATED AND MEASURED VALUES OF PEAK AMPLITUDES IN μV/METER

Source distance in km	Leader number	Stage I height in km	Calculated value	Measured value of Horner and Clarke
1	First	0.8	1440	1400
3	First Second Third	0.8 1.5 2.2	771 693 545	varies from 900 to 550
1 to 18	—	—	1440 to 133	1500 to 50

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[8] H. T. Friis, "Noise figure of radio receivers," PROC. IRE, vol. 32, pp. 419–422; July, 1944.

[9] F. Horner and C. Clarke, "Radio noise from lightning discharges," *Nature*, vol. 181, pp. 688–690; March, 1958.

[10] F. Horner, "The relationship between atmospheric radio noise and lightning," *J. Atmos. Terres. Phys.*, vol. 13, pp. 140–154; December, 1958.

Experimental Proof of Focusing at the Skip Distance by Backscatter Records*

For some years, the fieldstrength near the skip distance and its variation with time and space has been the subject of different calculations[1–3] and measurements,[4,5] but the focusing which was expected has not yet been proved in an unequivocal manner. However, this seems to be a result of technical rather than other difficulties.

For more than half a year, we have made backscatter records every day, on a fixed frequency of 16.65 mc. The film speed was low, so the time scale was rather narrow; with a pulse duration of 100 μsec we had a good resolution of distances.

In spite of the poor information we have with respect to ground scatter, it seems that backscatter observations are quite useful for our problem because focusing must be active twice whenever it occurs, *viz.*, on the direct as well as on the return way. In fact, clear focusing has been observed nearly every day for some time, often for many hours and for both magneto-ionic components [Fig. 1(a)].

The effect of focusing was less pronounced in summer than in winter. Also, the focusing phenomena observed at Breisach near Freiburg were less frequent and less important when observations were made in the direction of 250° (South-West) and especially 280° (West) than they were in the direction of 220° (South). These variations according to season and direction can be adequately explained by the following facts: the ionospheric turbulence should be greater in a northern direction; the disturbance of geometrical optics by the existence of Es layers must be more important in summer; and the defocusing effect of the refraction by the normal E layer[6] should be greater in summer.

Occasionally we found a clear focusing even for the two-hop rays (2F.); in these cases the difference of the skip distance for both components is twice that for 1F. This can be seen from Fig. 1(b).

Note with respect to the records that we use a 66-cps pulse recurrence frequency at the transmitter side, but 33 cps for the receiver sweep; only half of this sweep (corresponding to 2250 instead of 4500 km) is recorded, *viz.*, the delay between two successive transmitter pulses (dark lines at the lower and upper margin of the record). Thus we have an overlapping of two reflection patterns. Distinction of both patterns is made possible by switching the transmitter to 33 cps; this is done for a two-minute interval every quarter of an hour. The 1F. backscatter is the lower trace in Fig. 1(b) which has the quarter-hourly interruptions. It belongs to a pulse which was 1/66 second

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* Received by the IRE, October 19, 1959.

[1] H. Bremmer, "Terrestrial Radio Waves," Elsevier, New York, N. Y., pp. 182–190; 1949.

[2] K. Rawer, "Calcul du champ de l'onde d'espace," *Rev. Sci.*, vol. 85, pp. 234–235, February, 1949; pp. 287–288, March, 1947; pp. 361–362, April, 1947; vol. 86, pp. 481–485, June, 1948; pp. 585–600, October, 1948.

[3] H. Poeverlein, "Fieldstrength near the skip distance," AF Cambridge Res. Center, Bedford, Mass., Tech. Rept. No. TR-54-104; 1955.

[4] J. Grosskoph, "Über einige Beobachtungen bei Feldstärkeregistrierungen im Kurzwellenbereich," Telegr., Fernspr., Funk und Fernseh-tech., vol. 29, pp. 127–137; May, 1940.

[5] B. Bechmann, W. Menzel, and F. Vilbig, "Grenzwellen und Streustrahlung in der Funkausbreitung," Telegr., Fernspr., Funk und Fernsehtech., vol. 30, pp. 43–52; February, 1941.

[6] K. Bibl, K. Rawer, and E. Theissen, "Le Rôle de L'occultation dans la Propagation des Ondes Décamétriques," Rapport du Service de Prevision Ionospherique, France, No. R11; December, 1951. Also, "An improved method for the calculation of the fieldstrength of waves reflected by the ionosphere," *Nature*, vol. 169, pp. 147–150; January, 1952.

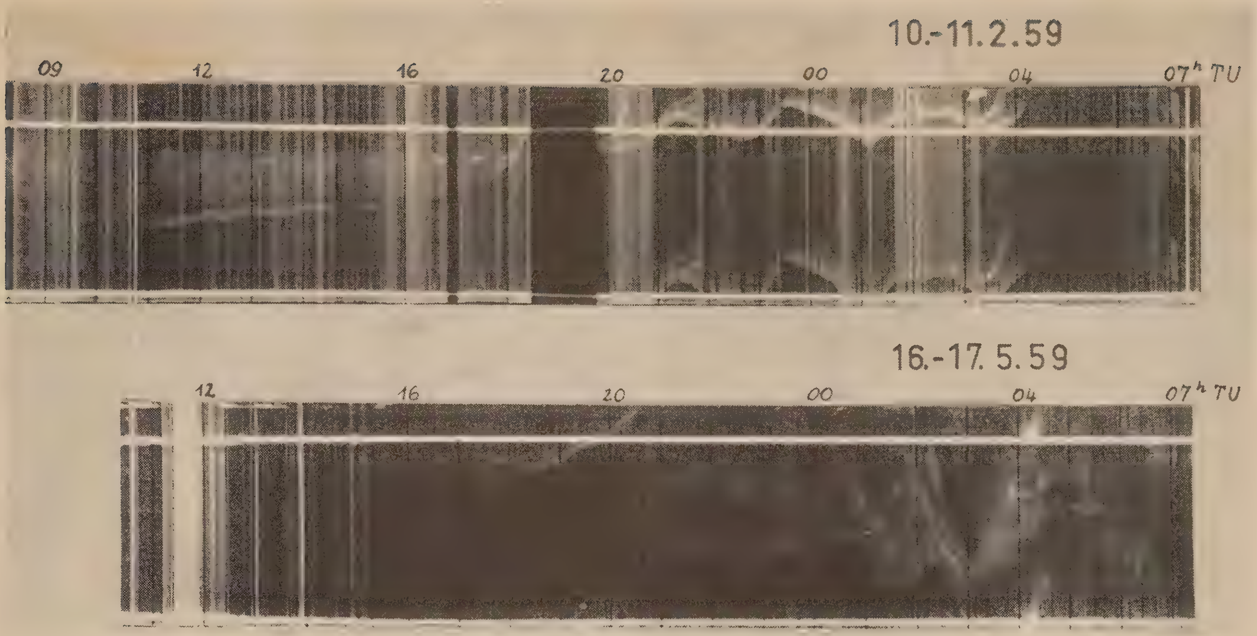

Fig. 1—Records (markers correspond to one hour and 150 km. (a) Winter focusing (10/11.2.59); (b) focusing on 1F. and 2F. (16/17.5.59).

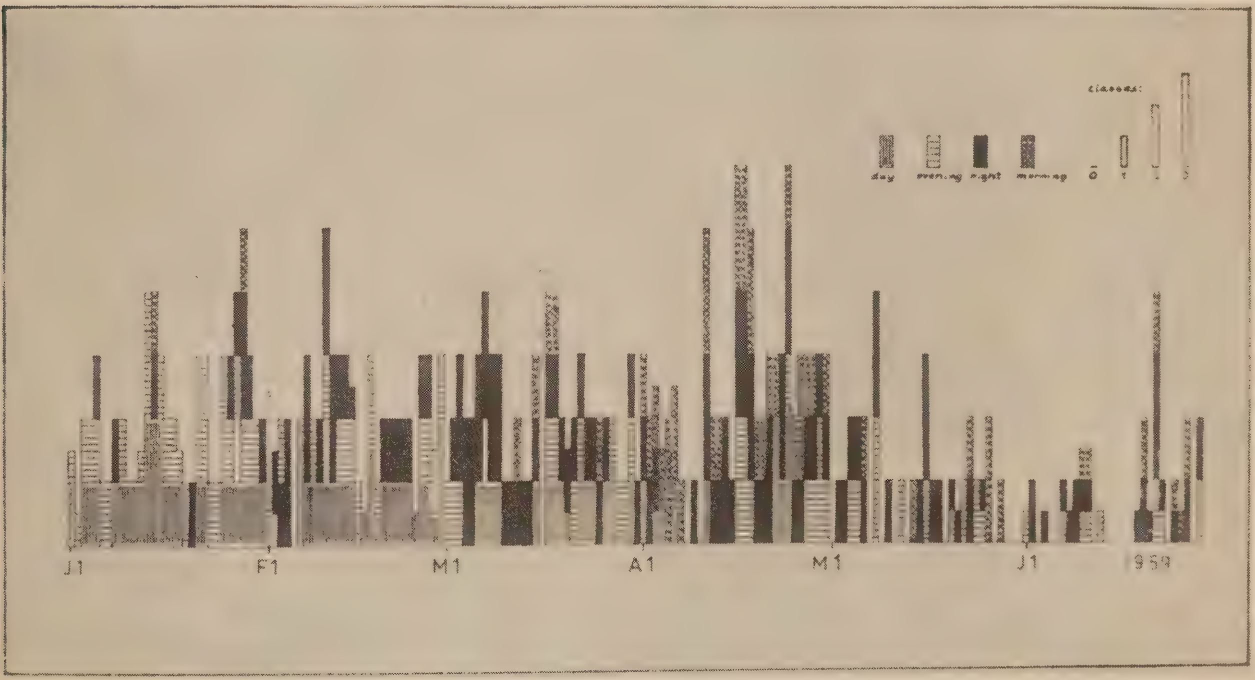

Fig. 2—Statistical results for the South and South-West directions.

below the lower black line; thus we must add 2250 km to the range as measured from this line. The 2F. backscatter is the upper trace in Fig. 1(b). The corresponding pulse is 2/66 second below the lower black line, so we must add 4500 km. In our example, the 2F. backscatter came from a distance of 5000 to 6000 km; this is about the distance from the United States to Freiburg.

In order to give a general view of the frequency of focusing, Fig. 2 gives day-to-day statistics for the last six months. Four periods of the day been represented separately (four colors). The importance of focusing has been classified in four grades: 0 = no focusing; 1 = weak focusing; 2 = both components distinctly visible at skip distance; 3 = lasting a long time and components distinctly visible. On our frequency, daytime focusing was only present in winter, nighttime focusing was most frequent in spring; the over-all importance decreased in summer.

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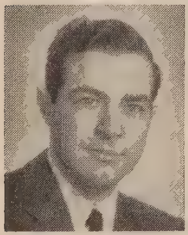
F. R. Arams

Frank R. Arams (S'44–A'49–SM'55) was born on October 18, 1925 in the Free City of Danzig. He received the B.S.E. degree in electrical engineering and mathematics from the University of Michigan, Ann Arbor, in 1947; the M.S. degree in applied physics from Harvard University, Cambridge, Mass., in 1948; and the M.S. degree in business management from Stevens Institute of Technology, Hoboken, N. J., in 1953. He is presently completing the requirements for the doctorate degree in electrical engineering at the Polytechnic Institute of Brooklyn, Brooklyn, N. Y. His dissertation concerns an investigation of new types of solid-state masers employing harmonic spin coupling effects.

During World War II, he served in the Army Signal Corps as communications chief of Radio Receiver Station WXH, Ketchikan, Alaska. He joined the Radio Corporation of America, Lancaster, Pa., in 1948, where he was project engineer on various development programs on microwave magnetrons, traveling-wave tubes, and plasma-filled cavities. From 1953 to 1956, he was employed at RCA Tube Division, Harrison, N. J., where he was in charge of the microwave tube application engineering group. In 1956, he joined the Airborne Instruments Laboratory, a division of Cutler-Hammer, Inc., Melville, L. I., N. Y., where he is presently associated with the department of applied electronics as Consultant, and is concerned with theoretical and experimental work on microwave solid-state devices, such as new types of solid-state maser amplifiers, microwave ferrite devices, etc. He is presently directing advanced programs in the microwave ferrite and traveling-wave maser fields.

Mr. Arams was a 1944 Donovan Scholar at the University of Michigan, and is a member of Tau Beta Pi, Eta Kappa Nu and the American Physical Society.

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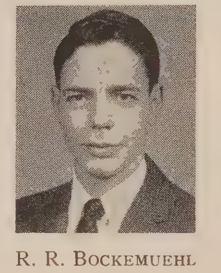
R. R. Bockemuehl

Robert R. Bockemuehl was born in Omaha, Neb., on October 17, 1927. He received the B.S.E.E. degree from the University of Michigan, Ann Arbor, in 1952.

He has worked at the General Motors Research Laboratories, Warren, Mich. since 1952. Until 1958, his activities primarily included development of highly specialized instrumentation and control systems for use in scientific measurements and automotive testing. He is currently a Senior Research Engineer in the Physics Department of the General Motors Research Laboratories where he is engaged in basic and applied research in the field of solid-state electronic devices and compound semiconductor materials.

Mr. Bockemuehl is a member of Tau Beta Pi, Eta Kappa Nu and Phi Kappa Phi.

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K. K. N. Chang

Kern K. N. Chang was born in Shanghai, China, on September 9, 1919. He received the B.S. degree from the National Central University, Nanking, China, in 1940, the M.S.E.E. degree from the University of Michigan, Ann Arbor, in 1948, and the D.E.E. degree from the Polytechnic Institute of Brooklyn, N. Y., in 1954.

From 1940 to 1945, he was associated with the Central Radio Manufacturing Works, Kunming, China, working on radio receivers. From 1945 to 1947, he was a radio instructor in the Office of Strategic Services, U. S. Army, China Theater. Since 1948, he has been at RCA Laboratories, Princeton, N. J., where he has been engaged in research on magnetrons, traveling-wave tubes, beam-focusing devices, and parametric and tunnel-diode devices.

Dr. Chang is a member of Sigma Xi.

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J. W. Coltman

John W. Coltman (SM'49–F'55) was born in Cleveland, Ohio, on July 19, 1915. He received the B.S. degree in physics from Case Institute of Technology, Cleveland, in 1937, and the Ph.D. degree from the University of Illinois, Urbana, in 1941.

He joined the Westinghouse Research Laboratories, Pittsburgh, Pa., in 1941, and spent the war years in research and development on microwave magnetrons. In 1946, he organized a group to undertake the development of a means to increase the brightness of fluoroscopic X-ray images. It was during the course of this work that he invented, with Fitz-Hugh Marshall, the scintillation counter. The project culminated in the first successful X-ray image amplifier, the Fluorex. Since 1949, he has been manager of the Electronics and Nuclear Physics Department of the Westinghouse Laboratories, guiding and participating in programs concerned with infrared and optical imaging, communications, underwater acoustics, microwaves, electron physics, solid-state physics, and nuclear physics.

Dr. Coltman has been a member of the Board of Editors and an Editorial Reviewer for the IRE, and is a Fellow of the American Physical Society and member of Tau Beta Pi and Sigma Xi.

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C. A. Desoer

Charles A. Desoer (S'50–A'53–SM'57) was born in Brussels, Belgium, in 1926. He received the radio engineer's degree from the University of Liége, Belgium, in 1949. He went to Massachusetts Institute of Technology, Cambridge, and obtained the D.Sc. degree in 1953. He joined the Bell Telephone Laboratories, where he worked in the transmission systems group, principally in the field of network theory. In 1958, he joined the Department of Electrical Engineering at the University of California, Berkeley. His main interest lies in systems and communication theory.

Dr. Desoer is a member of Sigma Xi.

J. H. Dietz

James H. Dietz (S'51–A'52–M'57), was born in Baltimore, Md., on January 18, 1927. He received the B.S. degree in physics from Loyola College, Baltimore, Md., in 1950 and the M.S.E.E. degree from the University of Pennsylvania, Philadelphia, in 1959.

From 1951 to 1953 he worked at the Radiation Laboratory of The Johns Hopkins University, Baltimore, where he was a member of a group engaged in the development of proximity-fuze circuits. Later, from 1953 to 1956, he was employed by the Bendix Radio Division, Towson, Md., working on the development of missile-guidance systems. He is presently a research associate on the staff of the Moore School of Electrical Engineering, University of Pennsylvania.

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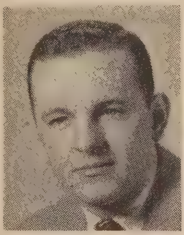

G. H. Heilmeier

George H. Heilmeier (S'58) was born in Philadelphia, Pa., on May 22, 1936. He received the B.S.E.E. degree from the University of Pennsylvania, Philadelphia, in 1958, and is presently a candidate for the Doctor's degree at Princeton University, Princeton, N. J., under the sponsorship of RCA Laboratories.

Since 1958, he has been working in the general area of solid-state microwave dedevices with emphasis on distributed parametric structures, and he will receive the M.S. degree from Princeton in June, 1960, for his contributions in this area. He has also investigated the generation of millimeter waves by parametric methods.

Mr. Heilmeier is a member of Sigma Xi, Tau Beta Pi, and Eta Kappa Nu.

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Y. H. Ku

Y. H. Ku (SM'53), was born in Wusih, China on December 24, 1902. He received the B.S. degree in 1925, the M.S. degree in 1926, and the D.Sc. degree in 1928, all from the Massachusetts Institute of Technology, Cambridge.

From 1932 to 1937, he was dean of Engineering, Tsing Hua University, Peiping, China, and from 1944 to 1945, he was president of Central University, Chungking, China. During World War II, he served as Vice-Minister of Education in the National Government of the Republic of China and later served as Commissioner of Education, Shanghai. He is presently a professor at the Moore School of Electrical Engineering, University of Pennsylvania, Philadelphia.

Dr. Ku is a fellow of the AIEE and the Academia Sinica, and is an elected member of the General Assembly of the International Union of Theoretical and Applied Mechanics. He is also a member of Sigma Xi and Eta Kappa Nu.

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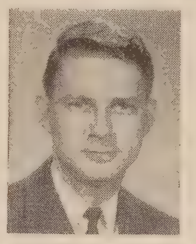

P. R. McIsaac

Paul R. McIsaac (A'59) was born on April 20, 1926, in Brooklyn, N. Y. He received the B.E.E. degree from Cornell University, Ithaca, N. Y., in February, 1949, after serving for two years in the U. S. Navy. He received the M.S.E. and Ph.D. degrees from the University of Michigan, Ann Arbor, in 1950 and 1954, respectively. During 1952, he was engaged in studying ferromagnetic metals at high frequencies at the University of Leeds, England.

From 1954 to 1959, he was employed by the Sperry Gyroscope Co., Great Neck, N. Y. where he worked on problems associated with the microwave circuits and the interaction theory for microwave tubes. At present, he is an associate professor of electrical engineering at Cornell University.

Dr. McIsaac is a member of Sigma Xi.

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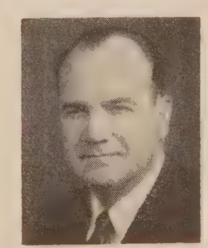

W. W. Mumford

William W. Mumford (A'30–SM'46–F'52) was born in Vancouver, Wash., on June 17, 1905. He received the B.A. degree in 1930 from Willamette University, Salem, Ore., majoring in physics and mathematics. He served in the U. S. Coast Guard as a radio operator on the Cutter *Algonquin* in 1923 and 1924, and as a telegraph operator, clerk and manager with the Western Union Telegraph Company, in Washington and Oregon during the next two years. From 1928 to 1930, he was associated with the Oregon State Highway Commission Testing Laboratory. In 1930, he joined the Technical Staff of the Bell Telephone Laboratories with the Radio Research Department at Holmdel, N. J.

In 1953, he transferred to the Military Development Department of Bell Telephone Laboratories, Whippany, N. J., where he is now supervisor of a group engaged in the study of microwave radar problems and the exploratory development and exploitation of the latest techniques for improving noise figures of receivers.

He has worked on ultra-short-wave propagation and microwave components for radio relay systems and radars, and has studied the published literature concerning biological effects of microwaves as related to microwave radiation hazards. His contributions in the microwave field include the directional coupler, wideband coaxial-to-waveguide transducers, helix-to-waveguide transitions as used in the traveling-wave tube and the gas-discharge noise generator. These are covered in 31 published papers and 13 patents.

Mr. Mumford is a licensed Professional Engineer in New Jersey.

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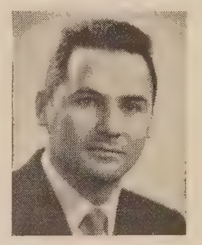
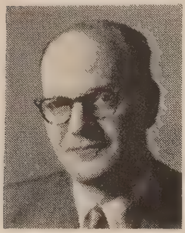


S. Okwit

Seymour Okwit was born on August 31, 1929, in New York, N. Y. He received the B.S. degree in physics from Brooklyn College, Brooklyn, N. Y., and the M.S. degree in applied mathematics and physics from Adelphi College, Garden City, N. Y., in 1952 and 1958, respectively. He is presently doing work toward the doctoral degree in mathematical physics.

From 1952 to 1954, he was in the armed forces. He was assigned to the detection division of the Chemical and Radiological Laboratories of the Army Chemical Center, Edgewood, Md., where he did extensive development work on instrumentation for the detection and analysis of the poisonous "G" nerve gases. Detection instruments that he worked on include an infrared scanning system and a system utilizing microwave spectroscopy. From 1954 to 1955, he was associated with the radar department of Arma Corporation, where he was concerned with boresight studies on monopulse antennas. He joined the Airborne Instruments Laboratory, a division of Cutler-Hammer, Inc., Melville, L. I., N. Y., in November, 1955, as an engineer in the Department of Applied Electronics, where he was concerned with the design and development of RF, IF, and microwave components and systems. Since 1958 he has been responsible for, and has performed considerable theoretical and experimental work on, solid-state devices such as low-loss circulators, low-level ferrite limiters, and cavity and traveling-wave masers. Mr. Okwit is now a group leader in the applied electronics department at AIL, and is currently directing programs in the development of advanced solid-state devices including masser, parametric amplifiers, and novel ferrite components.


H. J. Prager

H. John Prager was born in Vienna, Austria, in 1915. He received the B.S.E.E. degree from the University of Vienna in 1938 and the M.S.E.E. degree from the University of Michigan, Ann Arbor, in 1940. From 1940 to 1942, he was associated with the Research Laboratory of the Detroit Edison Company, Detroit, Mich. In 1943, he joined the Electron Tube Division of RCA in Harrison, N. J., as a production engineer of small power and receiving tubes. In 1944, he transferred to the Receiving Tube Development Group where he served as Design Engineer, Technical Coordinator, and Unit Leader until 1959. His various assignments there included the design of several entertainment-type receiving tubes as well as premium industrial tubes, gas-filled tubes and UHF pencil tubes. From 1954 until 1959, he served as a member of the JETEC-12 Committee, and also was an Evening Instructor at the Newark College of Engineering, Newark, N. J. He is presently engaged at the RCA Laboratories, Princeton, N. J., working on semiconductor-microwave devices.

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A. W. Straiton

Archie W. Straiton (M'47–SM'49–F'43) was born in Arlington, Tex., on August 27, 1907. He received the B.S.E.E. degree in 1929, the M.A. degree in 1931, and the Ph.D. degree in 1939, all from The University of Texas, Austin.

He taught at Texas College of Arts and Industries, Kingsville, from 1931 to 1943. Since 1943, he has taught at The University of Texas, Austin, where he is now Professor of electrical engineering and Director of the Electrical Engineering Research Laboratory.

Dr. Straiton is a member of Eta Kappa Nu, Tau Beta Pi, Sigma Xi and the American Society for Engineering Eduction. He was a former member of the U.S.A. National Committee and Chairman of Commission II of URSI.

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C. W. Tolbert

Charles W. Tolbert (M'49–SM'55) was born in Homer, La., on August 28, 1920. He received the B.S. degree in general engineering from Texas College of Arts and Industries, Kingsville.

He was employed for two years by the National Geophysical Company, Dallas, Tex., before coming to the University of Texas, Austin, as an instructor in 1945. Shortly afterwards, he joined the staff of the University's Electrical Engineering Research Laboratory, where he has been responsible for much of the experiment program, and, in recent years, has been in charge of the millimeter studies.

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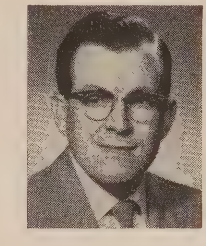
F. M. Turner

Franklin M. Turner (S'49–A'52–M'56) was born in Southington, Conn., on August 18, 1925. He received the A.A. degree from Grant Technical College, Del Paso Heights, Calif., in 1948. In 1950, he received the B.S. degree, and in 1951 the M.S.E.E. degree, both from Stanford University, Stanford Calif.

From 1951 to 1952, he studied microwave tubes as a research assistant with the Electronics Research Laboratory at Stanford University. In 1952, he became a staff member of this laboratory. He is currently a research associate with the Systems Techniques Laboratory, one of the five laboratories constituting the Stanford Electronics Laboratories at Stanford University. His present work is concerned with the development of new components and systems techniques related to electronic countermeasures.

Mr. Turner is an associate member of Sigma Xi.

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Chao C. Wang (A'43–SM'49–F'57) was born in Shanghai, China on October 20, 1914. He received the B.S.E.E. degree in 1936 from Chaio-Tung University, Shanghai, and the M.S. and Ph.D. degrees, both in radio communications, in 1938 and 1940, respectively, from Harvard University, Cambridge, Mass.

Since 1940, he has been engaged in microwave tube research and development. In 1940–1941, he studied vacuum tube manufacturing methods at the RCA Manufacturing Co., Harrison, N. J. During World War II, he worked on microwave tubes for radar applications at Westinghouse Electric Co., Bloomfield, N. J. Since that time he has worked in the investigation of problems in electron beam focusing by magnetic fields, and development of interaction and circuit theory of traveling-wave tubes. He has been Engineering Department Head for microwave tube research in the Sperry Electronic Tube Division, Sperry Gyroscope Co., Great Neck, N. Y., since 1956. In this capacity, he is also heading research in solid-state microwave electronics, thermionic emission, microwave gaseous plasma interaction, and computer development. He is also Victor Emanuel Professor at Cornell University, Ithaca, N. Y., for the Spring Term, 1960.

C. C. Wang

Dr. Wang is a member of the American Physical Society and the AAAS.

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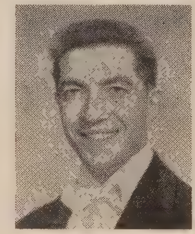
A. A. Wolf

Alfred A. Wolf (S'49–A'49–M'55), was born on July 21, 1925 in Philadelphia, Pa. He received the B.S.E.E. degree from Drexel Institute of Technology, Philadelphia, Pa., in 1948, the M.S.E.E. degree from the Moore School of Electrical Engineering, University of Pennsylvania, Philadelphia, in 1954 and the Ph.D. degree from the University of Pennsylvania in 1958.

From 1949 to 1954, he was on the staff of the Anti Submarine Warfare Division of the Naval Air Development Center. Then, from 1954 to 1959, he was associated with the Moore School of Electrical Engineering of the University of Pennsylvania. He joined the Stromberg-Carlson Division of the General Dynamics Corp., Rochester, N. Y., in 1959, where he is at present applying his theory of nonlinear systems to the development of a sophisticated fault detection theory in which he relates statistically measured quantities at the output of the system being tested to deterministic quantities determining the configuration of the structure in response to white noise.

Dr. Wolf has principally been interested in the theory of nonlinear systems and related stochastic processes and has published a number of papers on these subjects.

Books

Probability and Statistics, Ulf Grenander, Ed.

Published (1959) by John Wiley and Sons, Inc., 440 Fourth Ave., N. Y. 16, N. Y. 434 pages. 6×9¼. $12.50.

This book, subtitled "The Harald Cramér Volume," is a collection of studies in probability and statistics which was presented to Professor Cramér in honor of his 65th birthday. It is thus a somewhat heterogeneous collection of both exposition and research by some of the most eminent probabilists and statisticians throughout the world. The papers range from theory of estimation, nonparametric inference, and design of experiments in the field of statistics to Markov chain theory and Brownian motion in the fields of probability and stochastic processes.

A more exact view of the contents of this volume can be conveyed by listing the authors and titles: T. W. Anderson—Some Scaling Models and Estimation Procedures in the Latent Class Model; M. S. Bartlett—The Impact of Stochastic Process Theory on Statistics; J. L. Doob—A Markov Chain Theorem; G. Elfving—Design of Linear Experiments; W. Feller—On Combinatorial Methods in Fluctuation Theory; E. Fix, J. L. Hodges and E. L. Lehmann—The Restricted Chi-Square Test; U. Grenander—Some Non-Linear Problems in Probability Theory; M. Kac—Some Remarks on Stable Processes with Independent Increments; D. G. Kendall—Unitary Dilations of Markov Transition Operators, and the Corresponding Integral Representations for Transition-Probability Matrices; P. Lévy—Construction du Processus de W. Feller et H. P. McKean en Partant du Mouvement Brownien; P. Masani—Cramér's Theorem on Monotone Matrix-Valued Functions and the Wold Decomposition; P. Masani and N. Wiener—Non-Linear Prediction; J. Neyman—Optimal Asymptotic Tests of Composite Statistical Hypotheses; H. Robbins—Sequential Estimation of the Mean of a Normal Population; M. Rosenblatt—Statistical Analysis of Stochastic Processes with Stationary Residuals; C. O. Segerdahl—A Survey of Results in the Collective Theory of Risk; J. W. Tukey—An Introduction to the Measurement of Spectra; S. S. Wilks—Nonparametric Statistical Inference; H. Wold—Ends and Means in Econometric Model Building.

These collected papers fill 434 pages and represent a most interesting cross section of modern probability and statistics. The articles are carefully written and the authors have supplied excellent references to each of the topics, many of which were advanced by Cramér's researches.

Although this book was not written specifically by and for members of the engineering profession but rather by and for probabilists and statisticians, it will serve as a source of valuable material, especially to those engineers conducting investigations involving stochastic processes. For example, the papers by Bartlett, Kac, Lévy, Rosenblatt and Tukey will be of particular interest. The printing is excellent and great credit is due Ulf Grenander for his excellent work as editor. Thanks also should be given to John Wiley and Sons for publishing "The Harold Cramér Volume" during Professor Cramér's lifetime.

H. P. Edmundson
Planning Research Corp.
Los Angeles, Calif.

Materials and Techniques for Electron Tubes, by Walter H. Kohl

Published (1960) by Reinhold Publishing Corp., 430 Park Ave., N. Y. 22, N. Y. 603 pages+20 index pages+13 appendix pages+xvii paages. Illus. 6¼×9¼. $16.50.

"Materials and Techniques for Electron Tubes" is a revised and updated version of the former "Materials Technology for Electron Tubes" (1951) written as a reference book for tube engineers and scientists. Its seventeen chapters cover, in a remarkably complete manner, much of the vacuum tube materials work performed during the last decade. As stated by the author, "This . . . is not a textbook from which to learn first concepts, but it is a very useful reference book to be used in conjunction with other texts."

The book has chapters on glass, ceramic and mica materials. Metals are covered by chapters on carbon and graphite, iron and steels, copper, nickel, precious metals, tungsten, molybdenum, tantalum and niobium, and a chapter each on getters, brazing metals and cathode metals. Although materials application techniques are discussed throughout the various chapters of this book, individual chapters are devoted to glass-to-metal seals and ceramic-to-metal sealing. The latter chapter of forty-nine pages reflects the increasing importance of this type of seal to the tube industry and appears to be quite complete. The chapters on iron and steels, precious metals and getters are welcome additions. With the single exception of the chapter on Joining of Metals by Brazing, which has been condensed, all other chapters have been revised and greatly expanded.

As was the case in his earlier book, Dr. Kohl has compiled a comprehensive and valuable list of references for each of his chapters. Most of the reference material (nearly 1200 separate listings) has been published since 1952. Sufficient information is included in the references to permit one to locate the material quite easily.

The chapter on Precious Metals deals largely with the solution of grid emission problems and might well be expanded in a future edition. Similarly, the section on oxide-coated cathodes should be expanded, particularly with respect to the role of the nickel base alloys and the influence they have on cathode performance as a function of temperature, time, alloying elements, etc. A very good list of references is cited in this chapter. In general one might wish to see more information on the properties of materials at high temperatures in high vacuum; however, these data are very hard to locate, and in many cases the engineer or scientist must be guided by reported application experience.

The chapters on Ceramic-to-Metal Sealing and Tungsten are very well done and Table 12.1 entitled "Brazing Filler Metals for Electron Tubes," showing properties of 143 high temperature materials is an outstanding example of the factual information available throughout this book.

Dr. Kohl has written a very valuable comprehensive reference book which should be of great assistance not only to tube engineers but to others working with these materials as well.

A. P. Haase
General Electric Co.
Owensboro, Ky.

Mathematics for Communication Engineers, by S. J. Cotton

Published (1959) by the Macmillan Co., 60 Fifth Ave., N. Y. 11, N. Y. 229 pages+5 index pages+x pages+10 answer pages. Bibliography at end of each chapter. Illus. 6¼×10. $7.50.

The preface starts "It would be justifiable for anyone to exclaim: 'Another textbook on mathematics!' Yet this book was started in answer to a request from a number of students to bridge a gap which certainly does exist." On the one side is the mathematician with his proofs, and on the other side is the communications engineer needing to use advanced mathematics in his work. The book bridges this gap by giving developments of the ideas of advanced mathematics without always giving a full proof. Enough is given to make the result seem reasonable, and the results, especially in the early chapters of the book, are given in such a way that the communications engineer will find this a good book to use as a reference.

The topics covered are Review of Calculus, Determinants, Infinite Series, Trigonometric Functions, Complex Functions, Further Integration and Differentation, Differential Equations Applied to Lines and Networks, Theory of Functions of a Complex Variable, Harmonic Analysis, Vector Analysis, Special Functions and Equations, and Probability and Statistics. Each chapter contains examples of the application of the mathematics to a problem in communication engineering. There are exercises at the end of each chapter, and further exercises at the end of the book. Answers to the exercises are also given, so the book is well suited to self-study.

The book is well written and should be a real help to both students and practicing engineers. Once in a while the reader will run into wording which must be carefully studied. For example, in line 3 on page 142, reference is made to "any point in the region." Does the author mean that the condition he is imposing must apply to *all* points in the region, or only to *one* point in the region?

In the statement of the Laplace Transform (page 174) the same functional notation is used for the time-domain function, $f(t)$, and for the p-domain function, $f(p)$. This may be a mistake in typesetting, with $F(p)$ having been intended to show that these two are different functions as well as having different variables.

Some topics, such as matrix theory and advanced algebra, are not included in the book, nor are there any tables of functions.

The book is a compact package, reasonable in cost, with much advanced mathematics useful to the communications engineer. It lives up to its title quite well.

George B. Hoadley
North Carolina State College
Raleigh, N. C.

Telemetering Systems, by Perry A. Borden and W. J. Mayo-Wells

Published (1959) by Reinhold Publishing Corp., 430 Park Ave., N. Y. 22, N. Y. 331 pages+11 index pages+6 appendix pages+ix pages. Illus. 6¼×9¼. $8.50.

The field of telemetry is a rapidly expanding one. However, there are very few books on this subject. This book is therefore a welcome one and represents a modernization of a previous book by Borden and Thynell. The authors have made a particular effort to unify the older fields of industrial telemetry with the modern developments having application to aircraft and missile testing. It is particularly valuable in setting forth the components and concepts of industrial telemetering which are covered in the chapters on current, voltage and position systems of telemetering. There is an extensive section on the FM/FM system of telemetering which has considerable application in the aircraft and missile testing field. This, however, has been covered under the heading of "Frequency Systems of Telemetering."

The recent PCM system of telemetering is to be found in the chapter on "Impulse (Pulse) Systems of Telemetering." Also included in these chapters are the other pulse systems such as PPM, PDM, PAM, and two less known systems called Pulse Delta Modulation and Pulse Multiple Modulation.

The book also covers methods of reducing data collected by the telemeter in the chapters on Coordinating, Totalizing, Computing, and Integrating. The selection and application of telemetering systems are covered in a rather general way.

The manner of dealing with the subject matter is basically descriptive with some discussion of circuit details and block diagram configurations. There is little treatment from an analytic point of view of the design of telemetering equipment, of the analysis of bandwidth requirements and signal-to-noise considerations, or of the effect of interfering signals. Such considerations, for example, have been included in the radio telemetering field by Nichols and Rauch in their book "Radio Telemetry."

The authors have succeeded in their attempt to show the relationships between the older telemetering concepts and modern practice. However, some readers may find some difficulty in locating some of the newer systems in the framework of classification used in this book. The book will be found valuable to people working in the field because of the many examples of ingenious earlier practice in telemetry and will help people entering this field to become acquainted with the nature of telemetering devices.

Elliot L. Gruenberg
IBM Corp.
Bethesda, Md.

Modern Network Analysis, by F. M. Reza and Samuel Seely

Published (1959) by McGraw-Hill Book Co., Inc., 330 W. 42 St., N. Y. 36, N. Y. 361 pages+5 index pages+6 appendix pages+xi pages. Illus. 6¼×9¼. $10.00.

The objective of the authors in writing this book is to provide a link between available introductory texts (such as that of E. A. Guillemin and others) and the more mathematical works (of W. Cauer, R. M. Foster, and others). This text has been "classroom tested" and is intended for an advanced undergraduate or a first graduate course on the analysis and synthesis of linear networks. As is true of such texts, a considerable number of problems are given (with no answers).

The book is divided into three parts, the first of which comprises chapters on the complex s plane, matrices and determinates, network topology and equilibrium equations. Part II comprises three chapters devoted to application to two-port networks, image parameter and conventional filters, and linear systems with distributed parameters. The last, Part III, of the book comprises five chapters on the system functions of linear systems and their transient response to singularity functions, a brief review of Laplace transform theory, and realizability formulas in network synthesis.

The authors prefer to use the exponentially damped sinusoidal excitation e^{st} because the ensuing steady state response of a linear system differs from e^{st} only by multiplication by a complex quantity. They should have indicated, however, that a definable and separable steady state response can occur only for a nondamped sinusoidal excitation for which $s=jw$.

The chapter on linear algebra dealing with matrices and determinants is particularly useful as a body of formulas with applications. This also applies to the chapters on network topology and network equilibrium equations. A good description is given of the matric interrelationship among the six methods of analyzing two-port linear systems. It concludes with a review of the realizability criteria for linear systems from considerations of the energy functions using, in particular, the matrices described in the text.

The book is recommended to all students interested in network analysis.

Dr. M. J. DiToro
Polytechnic Res. and Dev. Co.
Brooklyn, N. Y.

Introduction to Matrix Analysis, by Richard Bellman

Published (1960) by McGraw-Hill Book Company, Inc., 330 W. 42 St., N. Y. 36, N. Y. 301 pages+6 index pages+19 appendix pages+xx pages. 6¼×9¼. $10.00.

To a very large extent, modern electrical engineering science is based on the concept of linearity. This is particularly true in the field of "systems" as opposed to "components." As a result of historical accidents as well as of the parochial attitudes of engineering educators in the past, the "linear systems" field is at present dominated by the Laplace transform, to the virtual exclusion of any other tool. This is as unfortunate as it is unnecessary. The growth of mathematics during the last century has given rise to an impressive body of knowledge based on linearity, which is nowadays usually called "linear algebra and analysis." Crudely speaking, linear algebra is matrix theory, and linear analysis is that class of problems (and much more) which engineers at present usually treat by the Laplace transform.

In the preface, the author calls matrix theory "the arithmetic of higher mathematics." For a scientific worker who is willing to use nontrivial mathematics (pure or applied), continued study of matrix theory deserves the highest priority. The reviewer feels strongly that matrix theory, as yet greatly neglected, belongs to the core of the engineering science curriculum. The reasons are: matrix theory is a theory of *complexity*, very useful in dealing with large networks, digital computers, etc.—areas where the Laplace transform is not well suited to cope with practical problems; it provides the rudiments of abstract language and thinking, without which the results of modern mathematics cannot be utilized.

The distaste of many engineers for matrix methods may be the result of inadequate expositions. Too many books have been written with the purpose of "selling" matrix methods, by concentrating on this or that application. On the other hand, texts in pure mathematics are unsuitable for engineering instruction because of complete lack of applications. So it is especially fortunate that the author of this book is an active leader in the fields of analysis and dynamic systems and has been concerned for many years with the delicate interplay between theory and applications. Equally fortunate for electrical engineers is the choice of subject matter, which is closely related in many cases to current applied problems. [Additional volumes are promised in this Series on 1) computational methods (by G. Forsythe), 2) linear programming and combinatorics (by A. Hoffman) and 3) network theory (by L. Weinberg).]

The book consists of short, brisk chapters, the main theme being quadratic forms. An outline of the contents is as follows:

Chapter 1 deals with maxima and minima of functions of two variables from several points of view.

Chapter 2 introduces matrix notation, transpose, inner product, etc.

Chapter 3 defines eigenvalues and eigenvectors and then applies these concepts to the diagonalization of symmetric matrices with distinct eigenvalues.

Chapter 4 begins with a detailed discussion of the Gram-Schmidt orthonormalization process and then completes the problem of diagonalizing symmetric matrices including simultaneous reduction of quadratic forms.

Chapter 5 considers maximization of quadratic forms subject to linear constraints. There is an interesting digression on partitioned matrices.

Chapter 6 is a quick look at functions of matrices, in cases where the matrix is diagonalizable. The integral of the Gaussian distribution is computed. Among the many interesting exercises is the Sylvester interpolation formula (No. 33) which can be regarded as the generalization of the partial-fraction expansions used in the theory of the Laplace transform.

Chapter 7 is devoted to the Rayleigh coefficient, the Fischer-Courant variational description of characteristic roots, etc.

Chapter 8 is a nice collection of inequalities, some not well known, such as those based on the formula for the Gaussian integral.

Chapter 9 is a quick, readable exposition of the elementary ideas of dynamic programming, from the point of view of matrices and quadratic forms.

Chapter 10 is perhaps of greatest interest to electrical engineers. It is concerned with linear matrix differential equations. Too many people do not yet know that the solution of the matrix differential equation $dx/dt = Ax$ can be expressed in the form $(\exp At) \times (0)$, a formula which is simpler and yet more general than the corresponding expression by Laplace transforms. Theorem 6 of this chapter (which goes back to Lyapunov) makes it possible to determine the integrated square of transient responses by solving a set of linear algebraic equations—this is at present usually done by means of cumbersome tables.

Chapter 11 deals with explicit representations of matrices and matrix functions, Jordan canonic form, normal matrices, etc.

Chapter 12 is a very brief look at Kronecker sums and products—these are of interest in recent research in stability theory, random processes, etc.

Chapter 13 is a study of stability in linear systems, based mainly on the theorem of Lyapunov in Chapter 10. This is the modern approach to the Routh-Hurwitz criteria and deserves further serious study, particularly by control engineers.

Chapter 14 is concerned with Markov chains and processes from the matrix point of view.

Chapter 15 is an ultra-short (because so little is known) note on the theory of linear dynamic systems whose defining parameters change randomly with time.

Chapter 16 deals with matrices with positive elements, illustrating their significance by some typical problems from mathematical economics.

There are four appendixes; one dealing with the solution of linear algebraic equations, and the remaining three with somewhat advanced special topics in quadratic forms.

The problems and bibliographical comments should be singled out for special praise. The former, some frivolous, some straightforward, some important recent results or tricks, are highly educational for those who aim at mastery of the subject, but do not sidetrack the beginning student. The references include the "classical" papers, at least since the 1940's and are also very useful in getting started on new research.

This is a superb book and is warmly recommended. Its wealth of material and modern point of view should appeal to the specialist. As most of the exposition is elementary, it should be well received as a text for the classroom or self-study, at about the senior or first-year graduate level.

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The Theory of Optimum Noise Immunity, by V. A. Kotel'nikov (translated from the Russian by R. A. Silverman)

Published (1959) by McGraw-Hill Book Co., Inc., 330 W. 42 St., N. Y. 36, N. Y. 140 pages+xi pages. Illus. $7\frac{1}{4}\times10\frac{1}{4}$. $7.50.

Vladimir Aleksandrovich Kotel'nikov is one of the few electronics engineers ever to be elected Academician in the Academy of Sciences of the U.S.S.R. In 1947 he published a doctoral dissertation which was subsequently republished in book form in Russian. R. A. Silverman's excellent translation of this Russian classic should be of interest to English speaking communications engineers for both technical and historical reasons.

Kotel'nikov deals with the problem of analyzing the performance of various communication systems in the presence of additive Gaussian noise. This performance is measured by minimum probability of error in the case of discrete messages and minimum mean square error in the continuous case. The organization of this little book is as neat and concise as Kotel'nikov's mathematics. Part I serves to set the framework of the problems considered and to sharpen the few mathematical tools used in the rest of the book. Part II then treats the transmission of discrete messages, Part III the transmission of a continuous parameter value and Part IV the transmission of continuous time functions. Each of the latter three parts is peppered with examples of the application of the general theory to special types of communication systems—AM, FM, PAM, PPM, SSB, etc.

At a time when the space lag is exciting so much comment, it is interesting to examine this volume with a view to the possible existence of a "communication theory lag." The framework within which Kotel'nikov solves his problems is one which we now call statistical decision theory. Statistical decision theory was developed in this country by Wald shortly before Kotel'nikov first published his results in 1947. It was eight years later, however, before Middleton and Van Meter became the first to apply Wald's ideas to communication problems in this country.

Two other Sputniks of note in this volume are the geometrical interpretation of signals and the analysis of nonwhite noise filtering problems by the use of inverse filters. The former was first published in this country by Shannon in 1949, the latter by Bode and Shannon in 1950.

It seems fair to say that at the present time there is no single major concept (with the possible exception of the material in section 9-2) in Kotel'nikov's work which is not known in this country. As noted above, this was not true as little as five years ago. This is not to say that the results have all been worked out in this country—they have not.

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The Electric Arc, by J. M. Somerville

Published (1960) by John Wiley and Sons, Inc., 440 Fourth Ave., New York 16, N. Y. 134 pages+7 index pages+9 bibliography pages+ix pages. 38 figures. $4\frac{1}{4}\times6\frac{3}{4}$. $2.50.

The author of this interesting little book has made an important and useful addition to the Methuen series of monographs on physical subjects. Although the preface states that the monograph attempts to give a brief account of this " . . . well known, but by no means well understood, phenomenon" it really accomplishes much more. The various aspects selected for discussion are very well chosen and represent the most important aspects of our present knowledge of the subject. Clear physical interpretations are substituted for the extensive and detailed treatment of original sources. The figures are simplified, but present clearly the essential facts under consideration.

The first chapter is a brief introduction section that reviews the over-all characteristics of arcs. Following this, Part I covers the phenomena of "the stable arc" in two chapters. The first of these covers the principal phenomena and theory of the long column; such as the energy balance in a plasma in thermal equilibrium, the Gerdien (or vortex) arc, the column gradient over four decades of pressure, the column temperature over six decades of pressure, electron density, energy transfer, and radiation, use as light sources in lamps, and concluding with a short section on the possibility of thermonuclear reaction in arcs.

The second chapter of Part I (Chapter 3) contains a brief, authoritative treatment of the basic phenomena associated with arc electrodes. The best theories of the cathode spot are presented together with pertinent experimental data. Anode phenomena and electrode-vapor jets are discussed in short sections.

Part II (Chapters 4 and 5) is entitled "The Approach to the Stable Arc." The first chapter discusses the transient phenomena of the "spark" as it develops into a stable arc. Chapter 5 considers briefly the transition from a glow discharge to an arc, and the formation of an arc by separating current-carrying contacts.

The book concludes with a list of 186 important references, an author, and a subject index.

Professor Somerville's book will quickly and accurately orient the newcomer to the field with the best experimental and theoretical knowledge of the electric arc as it is now understood.

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Sound in the Theatre, by Harold Burris-Meyer and Vincent Mallory

Published (1959) by Radio Magazines, Inc., Mineola, L. I., N. Y. 92 pages+3 index pages. Illus. $8\frac{1}{2}\times10\frac{1}{2}$. $10.00.

The authors of this book have pioneered in the use of modern equipment and techniques for sound control and special sound effects for drama and opera in live theatrical production. This book brings their experience to the neophyte, whether he is a theatrical person needing practical technical knowledge, or an experienced engineer making his first entrance into the complex artistic realm. After a brief summary of basic facts of acoustics, there are chapters on architecture and scenery, sources and pickup of sound, control techniques, systems, input equipment, output equipment, organization and planning, and installation and use. Much of the information is specific to theatrical productions which the authors have assisted. The book may leave the reader asking questions, but it is an interesting introduction to the borderline field between electrical engineering and the theatrical arts.

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The Physics of Television, by Donald G. Fink and David M. Lutyens

Published (1960) by Doubleday and Company, Inc., 575 Madison Ave., N. Y. 22, N. Y. 153 pages+7 index pages. 44 figures. 4¼×7¼. paperbound. $0.95.

This is a very remarkable book. It attempts in 150 pages and with practically no mathematics to present the story of television to the layman, up to and including color.

It starts with the brain wave associated with thought and surveys various forms of transmission of that thought, starting from hand signals up; explaining the limitations of each form and why more sophistication is desirable. The description of the technique of coding and scanning for television is excellent.

The discussion of basic physics is well written and really tries to make things simple and understandable to the layman. To my mind it is too detailed and presents concepts too difficult for the reader. The concept of electron jumps of different energy content is a very difficult one (particularly without mathematics) and I believe could well be skipped. Assumptions are made that the reader is already familiar with a transformer and that he knows a spiral drawing represents a coil of wire or maybe a transformer winding. As an old-time teacher I know that interpretation of symbolic diagrams is not easy and requires both explanation and practice. It has the fastest discussion of alternating current this reviewer has ever seen.

It seemed to me when I read the book that it was much too conceptually complex for the average reader, even though beautifully organized and written. Although I believed that if anyone could achieve this aim the present authors could, I was about to dismiss it as another "experiment noble in purpose."

To confirm my judgment, I lent the book to a friend who had no physics except in high school some years ago. To show how wrong I was I received this note, "Many thanks for the chance to read this book. I will buy a copy and continue reading—think it is excellent."

Imagine my confusion!

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Class D Citizens Radio, by Leo G. Sands

Published (1960) by Ziff-Davis Publishing Co., 1 Park Ave., N. Y. 16, N. Y. 133 pages+3 index pages +38 appendix pages+x pages. Illus. 6¼×9¼. $4.95.

According to this book, the FCC in mid-1959 was processing 5000 applications per month for Class D citizens radio station licenses. This extraordinary activity may give some idea of the popularity of this radio service whereby any United States citizen over 18 years of age may install and operate a two-way private radiotelephone in his car, plane, boat or camp, home, or office.

The book explains in essentially nontechnical language what this service is all about, how to get into it, how to buy and install and operate the equipment.

It is an excellent book for the radio engineer to recommend when he is asked to advise anyone on any aspect of the Class D portion of the so-called citizens radio spectrum. It is not a design book, nor a how-to-do-it book. It tells the reader what equipment is available, how much it costs, and the rules and regulations governing its use.

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Millimicrosecond Pulse Techniques, by I. A. D. Lewis and F. H. Wells

Published (1960) by Pergamon Press, 122 E. 55 St., N. Y. 22, N. Y. 360 pages+3 index pages+1 bibliography page+29 reference pages+22 appendix pages. Illus. 5½×8¾. $8.50.

Since its original publication in 1954, this book has enjoyed great popularity among physicists and electronic engineers as a ready reference on fundamental aspects of electronics and networks in the millimicrosecond range. The text of this newest second edition has been considerably revised and abounds with the latest advances including a special treatment of transistor switching techniques. It is a very welcome addition to the International Series of Monographs on Electronics and Instrumentation. It is intended to cover, in the words of the authors, "developments in the theory and design of electronic circuits and devices for operation in the range of time intervals which lie between the province of microsecond pulse circuits and the realm of microwave devices."

Some idea of the scope of the book can be obtained from the headings of the eight chapters into which it is divided. These chapters are entitled, "Theoretical Introduction," "Transmission Lines," "Transformers," "Pulse Generators," "Amplifiers," "Cathode Ray Oscilloscopes," "Applications To Nuclear Physics," and "Miscellaneous Applications."

Under "Theoretical Introduction," the reader is briefly guided into the domain of circuit analysis involving both sinusoidally varying and pulse waveforms. Fourier's Theorem is illustrated, the method of Laplace Transforms elaborated upon, and the importance of approximations stressed. The chapter concludes with remarks on the handling of switching phenomena and circuits with distributed parameters. In the latter, phase distortion rather than amplitude distortion may well determine the useful bandwidth.

The chapter on "Transmission Lines" contains an extremely wide range of topics covering conventional distributed circuit analysis, effects of discontinuities, pulse shaping, and the influence of loss. Also, a very interesting treatment of helical delay lines is given in addition to limitations of lumped delay lines.

The role of distributed lines as pulse transformers is extensively described in the chapter on "Transformers" and includes an analysis of smooth tapered lines, the Gaussian line, the exponential line, and the linearly tapered coaxial line. It is followed by a compact description of special transformers composed of coaxial lines, such as the pulse inverter, stacked-line transformers, and a filament isolating transformer as well as an introduction to coupled-line transformers.

The treatment of "Pulse Generators" represents a remarkable review of the literature on diverse aspects dealing with basic concepts and principles. The major topics relate to discharge line type pulse generators, pulse generators employing secondary emission tubes, recycling pulse generators, attenuators, and pulse measuring equipments. The range includes microwave pulses.

The problem of amplifying pulses is considered under "Amplifiers" following a discussion of high-frequency limitations of conventional electron tubes and conventional circuits. Basic difficulties and inherent advantages are carefully described in connection with interstage coupling, cascade amplifiers, distributed amplifiers, and bandpass amplifiers, including traveling-wave tubes and the possibility of using modulated microwave carrier systems.

The introductory material in the chapter on "Cathode Ray Oscilloscopes" emphasizes transit-time limitations and methods for obtaining high deflection sensitivity. It is followed by selected topics relating to transient recording oscilloscopes, oscilloscopes for the display of recurrent waveforms, and oscilloscopes for recurrent pulses using pulse sampling techniques.

A detailed treatment of applications is contained in the chapter entitled "Applications to Nuclear Physics" and is continued in the last chapter on "Miscellaneous Applications." The first of these two chapters is devoted to measuring problems encountered in nuclear physics research and special mention is made of scintillation counters, spark counters, amplitude discriminators, fast scaling circuits, coincidence circuits, time interval measurement by integration methods, and recording oscilloscope measurements. The last chapter considers a number of other applications, mainly, pulse generators for narrow bandwidth radio receiver measurements, peculiarities of waveguide and cable testing, the Wamoscope, the measurement of time jitter in trains of video pulses, analysis of modulated electron beams and transistors in fast switching circuits.

The authors are to be commended for bringing to the attention of physicists and engineers the present day capabilities of pulse circuits. The bibliography of each chapter is very complete and many references are detailed enough to offer specific information as to their value. The text will definitely ease the task of all who seek to become informed about pulse techniques. It is an excellent contribution, one of the most balanced and most illuminating studies yet made of this complex field.

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Scanning the Transactions

Human Factors in Electronics has become the 28th IRE Professional Group to commence publication of TRANSACTIONS, and its first issue starts off with a most provocative subject—man-computer symbiosis. Symbiosis is defined as a cooperative living together in intimate association of two dissimilar organisms. The hope is that in not too many years human brains and computing machines will be coupled together very tightly, and that the resulting partnership will think as no human brain has ever thought and process data in a way not approached by the information-handling machines we know today. In such a relationship the computer would no longer be confined to solving preformulated problems by means of predetermined programs, but would actively participate in the formulation of the very problems it must later solve and share, on a real-time basis, in the decision-making processes now performed by man alone. Man will still set the goals, formulate the hypotheses, determine the criteria and perform the evaluation, but the computing machine will do much of the routinizable work that must be done to prepare the way for insights and decisions. However, before the computer can enter into symbiotic association with man, man must first evolve a more sophisticated generation of computers with time-sharing capabilities, greatly improved memories and memory organization, a common man-machine language, and much improved input and output equipment. When these goals are reached—and they are within our eventual reach—man will be ready for what may prove to be intellectually the most creative and exciting chapter in the history of mankind. (J. C. R. Licklider, "Man-computer symbiosis," IRE TRANS. ON HUMAN FACTORS IN ELECTRONICS, March, 1960.)

Dual-unit transistors, reminiscent of multi-unit tubes, are making an entry into the semiconductor device field. A diode-triode transistor has been developed which consists of an alloyed *p-n* junction (diode unit) and an alloyed *p-n-p* junction (triode unit) constructed on one germanium pellet so that the *n*-type base region is common to both units. This construction provides direct connection between the diode and triode units and permits the use of fewer circuit components. The diode is intended for use as a detector and the triode as a Class A audio amplifier in a transistorized broadcast receiver. In addition to reducing the number of components re quired, the dual-unit transistor increases the detector efficiency of battery-operated receivers. (D. Thorne and R. V. Fournier, "Improvements in detection, gain-control, and audio-driver circuits of transistorized broadcast-band receivers," IRE TRANS. ON BROADCAST AND TELEVISIONS RECEIVERS, December, 1959.)

Research on research is an exciting and potentially fruitful new area of investigation which, it is hoped, will in time increase our understanding of and ability to manage the vital processes of Research, Development, and Engineering. It is a field that is in its early stages and the literature contributing to it is not yet readily accessible to the engineering manager—a void which the current issue of IRE TRANSACTIONS ON ENGINEERING MANAGEMENT makes a noteworthy effort to fill. In glancing through the papers in the issue one is struck by the fact that most of the authors are not engineers but rather are economists, sociologists, and operations researchers. Apparently, much of the initial motivation for doing "research on research" stems from an interest in economic factors, in social behavior, or simply in problems that are intriguing to analyze. One is also struck by the degree in which mathematical tools are being employed to analyze the affairs of humans. Thus one finds the authors speaking of such things as stochastic models, regression models, sets of sets, and logistic cubic functions in discussing the organization and operation of a research staff. Perhaps this is a sign that our understanding of the management process has progressed to a point where we are beginning to be able to formulate the problems to be solved. For before we can arrive at useful answers, we must first learn how to state the questions. (IRE TRANS. ON ENGINEERING MANAGEMENT, March, 1960.)

Active networks have a unique property: they can produce poles as well as zeros in the right half of the complex frequency plane. Such regenerative modes (exhibited in transient behavior as increasing exponentials) are essential for the operation of multivibrators, blocking oscillators, etc. In fact, the switching time, and thus the maximum repetition frequency, depends on the location of these right-half-plane natural frequencies. The farther away from the imaginary axis a regenerative mode is, the faster the operation possible. Now it turns out that if an RC network is used, the upper bound is fixed entirely by the physical active device and this upper bound can be easily computed directly from the active device. Not only is this extremely useful but it is satisfying to know tht it can actually be realized. (E. S. Kuh, "Regenerative modes of active networks," IRE TRANS. ON CIRCUIT THEORY, March, 1960.)

The powerful transistor. In view of the fact that transistors are essentially low-power devices, it is surprising to note how much power they can be called on to handle in switching applications. Germanium transistors having ratings up to 70 volts and 15 amperes having been introduced and developmental germanium devices with current-carrying capacities up to about 100 amperes have been made. More recently, silicon transistors and *n-p-n-p* devices (called Trinistors) have been developed which extend the power-handling capacity of semiconductor switches from the 1-kw limit of germanium Trinistors to the region of 10 kw. The extension of the current range of Trinistors, presently at 20 to 50 amperes, to 100 and 200 amperes is progressing rapidly. Indeed it appears feasible that power Trinistors may eventually be developed for use in inverter circuits operating in the 50 to 75 kva range. (H. W. Henkels and F. S. Stein, "Comparison of *n-p-n* transistors and *n-p-n-p* devices as twenty-ampere switches," IRE TRANS. ON ELECTRON DEVICES, January, 1960).

Abstracts of IRE Transactions

The following issues of TRANSACTIONS have recently been published, and are now available from the Institute of Radio Engineers, Inc., 1 East 79th Street, New York 21, N. Y. at the following prices. The contents of each issue and, where available, abstracts of technical papers are given below.

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Automatic Control

Vol. AC-4, No. 2, November, 1959

Papers Reprinted from Part 4 of the 1959 IRE National Convention Record

On Adaptive Control Processes—R. Bellman and R. Kalaba (p. 1)

One of the most challenging areas in the field of automatic control is the design of automatic control devices that "learn" to improve their performance based upon experience, *i.e.*, that can *adapt* themselves to circumstances as they find them. The military and commercial implications of such devices are impressive, and interest in the two main areas of research in the field of control, the USA and the USSR, runs high. Unfortunately, though, both theory and construction of adaptive controllers are in their infancy, and some time may pass before they are commonplace. Nonetheless, development at this time of adequate theories of processes of this nature is essential.

The purpose of the paper is to show how the functional equation technique of a new mathematical discipline, dynamic programming, can be used in the formulation and solution of a variety of optimization problems concerning the design of adaptive devices. Although, occasionally, a solution in closed form can be obtained, in general, numerical solution via the use of high-speed digital computers is contemplated.

Discussed here are the closely allied problems of formulating adaptive control processes in precise mathematical terms and of presenting feasible computational algorithms for determining numerical solutions.

To illustrate the general concepts, consider a system which is governed by the inhomogeneous van der Pol equation

$$\ddot{x} + \mu(x^2 - 1)\dot{x} + x = r(t), \quad 0 \leq t \leq T,$$

where $r(t)$ is a random function whose statistical properties are only partially known to a feedback control device which seeks to keep the system near the unstable equilibrium state $x=0$, $\dot{x}=0$. It proposes to do this by selecting the value of μ as a function of the state of the system at time t, and the time t itself. By observing the random process $r(t)$, the controller may, with the passage of time, infer more and more concerning the statistical properties of the function $r(t)$ and thus may be expected to improve the quality of its control decisions. In this way the controller *adapts* itself to circumstances as it finds them. The process is thus an interesting example of adaptive control, and conceivably, with some immediate applications.

Lastly, some areas of this general domain requiring additional research are indicated.

A Dynamic Programming Approach to Adaptive Control Processes—M. Freimer (p. 10)

In many multi-stage decision processes we face the problem of dealing with random variables whose distributions are initially imperfectly known, but which become known with increasing accuracy as the process continues. In this paper the author shows how Dynamic Programming may be used to treat a class of such problems, which are currently called *adaptive processes*.

After discussing the general theory, the techniques are illustrated by a specific example. For this example simple computation algorithms are derived, which are typical of those obtained for the whole class of problems under consideration.

On the Optimum Synthesis of Multipole Control Systems in the Wiener Sense—H. C. Hsieh and C. T. Leondes (p. 16)

This paper is concerned with obtaining the optimum system in the Wiener sense for the multipole system shown in Fig. 1. Earlier literature has shown how to obtain the mean-square value of the error when the multipole system transfer function has been specified, but thus far no published work has shown how to solve the synthesis problem, in general, for this case. The principal reason that this problem has appeared to be impossible of analytic solution thus far for cross correlation between the inputs is based on the fact that the usual variational approach results in a set of untractable simultaneous integral equations involving many complicated cross products of the desired weighting functions and the variational functions.

The synthesis problem for the system of Fig. 1 is first solved for the case in which there is no correlation between the inputs to the various terminals. The result for the optimum weighting functions in this case is presented in (24), and the resultant mean-squared value of the error is shown in (25).

Following this, the far more complicated case of the synthesis problem when the inputs to all the various terminals are correlated is considered. In this case, a rather unique technique is utilized to avoid the difficulties inherent in the use of the usual variational techniques. Through the technique utilized in this paper, the usual set of untractable simultaneous integral equations is completely avoided, and instead a set of ordinary algebraic equations results. The set of equations for this case is shown in (64), and in matrix form in (65). The resultant solution for the optimum physically realizable transfer functions is shown in (77). It is also shown, as a check, that the solution for the case of correlated inputs reduces to the solution obtained for the case of uncorrelated inputs.

The paper then concludes with an illustrative example for the more complicated case of correlated inputs. The possibilities of applications of the results of this paper to such fields as the guidance and control of astronautical vehicles, military fire control systems, bombing navigation systems, process control systems, automatic milling machines, air traffic control, nuclear reactor control, etc., are fairly evident.

On Adaptive Control Systems—L. Braun, Jr. (p. 30)

An attempt is made in the paper to evolve a basic philosophy for adaptive control systems.

A method is described for determining the system impulse response from measurements of instantaneous system input and output. The impulse response is expanded in a Taylor series, to facilitate solution of the convolution integral.

From a knowledge of the impulse response and the system error, the necessary correction to the system forcing function is determined, in a manner similar to that used for determination of the impulse response.

The techniques developed are applied to two systems—one stable and one unstable. Curves of the results are presented.

Extension of Phase Plane Analysis to Quantized Systems—P. H. Ellis (p. 43)

The increasing applications of numerical control of processes have created a need for new methods of synthesis of control equipment. The method presented is applicable to systems commanded by discretely valued inputs, and processes whose outputs may be similarly quantized. Periodic sampling is not required. The most suitable sampling is by transmission of only significant data, as the new value obtained when the data are changed by a given increment. In certain cases, transmission of data by this means can be used to increase channel capacity. When the data are so quantized, the error signal is constrained to a finite number of discrete values, each of which may be associated with an area on the phase plane. Within each such area, the trajectories of any process subject to phase plane representation are a family of parallel curves. Thus, analytic synthesis may be simplified in the case of certain nonlinear processes. Graphical design is facilitated without requiring deduction of a mathematical representation of the process.

The method is illustrated by synthesis of several systems involving a simple linear process.

Simplified Method of Determining Transient Response from Frequency Response of Linear Networks and Systems—V. S. Levadi (p. 55)

Knowing the frequency response of a linear system, a method is presented for obtaining the time response of the system to an impulse, step, or ramp function input, without performing graphical integrations.

The transient response is of the form

$$f(t) = \sum_i A_i G(\omega_i t)$$

where a different function G is used to determine the response to each of the three types of input.

Tables of the functions $G(x)$ are provided. An example is given to illustrate the simplicity and accuracy of this method. The results are compared with the exact time response.

A New Method of Analysis of Sampled-Data Systems—A. Papoulis (p. 67)

In many sampled-data systems the sampling interval T is "small" and the response $r_s(t)$ closely approximates the response $r(t)$ of the continuous system; one is then interested in evaluating the difference $r_s(t) - r(t)$ for various values of T. In this paper this difference is given as a power series in T whose coefficients can easily be determined in terms of the continuous response; if one wants to estimate the size of T for $r_s(t)$ to equal $r(t)$ within a specified error, the first term of this expansion will give an adequate measure of the error and hence of the maximum permissible T. Furthermore, since the resulting series converges rapidly, the expansion provides a simple method of evaluating $r_s(t)$ for a given T.

The method is applied to a feedback system with a sampler; the singularities of the p-rational system function that gives the actual response at the sampling points, are obtained by a displacement of the singularities of the continuous system function.

Statistical Filter Theory for Time-Varying Systems—E. C. Stewart and G. L. Smith (p. 74)

The guidance and control accuracy of most aerodynamic and space vehicles is limited primarily by the noise disturbances which enter the guidance system. Present theory for the minimization of these noise effects does not take into account the forced kinematic time variations, such as is due to time-varying range, which occur in most guidance problems. Such time variations occur in interplanetary flight, satellite rendezvous, interception of missiles or bombers, and so forth. In this paper an analytical approach is presented for the optimization of systems which are forced both to be time varying and to operate with inputs contaminated with noise.

Two objectives are the establishment of the theoretical optimum performance and a method of synthesizing the optimum control system. Effects of restrictions on the capability of the output element in addition to the noise and the forced time variation are considered. Although an exact analytical solution of the problem does not appear feasible, it is shown how approximate solutions utilizing time-varying control systems can be found. The method is illustrated by a hypothetical example of a homing missile attacking a bomber.

On the Phase Plane Analysis of Nonlinear Time-Varying Systems—R. F. Whitbeck (p. 80)

A phase plane technique, which takes advantage of convenient relationships in other planes (for example, displacement versus time) to effect graphical solutions for a nonlinear time varying second order differential equation, is developed. Several special cases of this general second order equation are considered. The special case of most practical importance occurs when the differential equation is permitted to become piecewise linear. To demonstrate the simplicity of the technique, for the piecewise linear case, an example involving saturation in an inertially damped position servomechanism is given.

On the Use of Growing Harmonic Exponentials to Identify Static Nonlinear Operators—H. J. Lory, D. C. Lai and W. H. Huggins (p. 91)

The paper describes a method of obtaining a polynomial characteristic function for a nonlinear static system. This function,

$$F(x) = hx + mx^2 + dx^3,$$

is obtained by the application of a growing exponential $x = \exp(t)$ to the input of the system and the filtering of the output

$$h \exp(t) + m \exp(2t) + d \exp(3t),$$

into its separate components $h \exp(t)$, $m \exp(2t)$, and $d \exp(3t)$. The values of these three components at $t = 0$ are the polynomial coefficients h, m, and d respectively. The identification of systems not exactly describable by a cubic gives rise to an error minimization problem; the technique described in this paper minimizes the weighted mean-square error, with a weighting function $1/x$. This method is compared with the more widely known sinusoidal analysis of nonlinear systems. Experimental results are given.

Papers reprinted from Part 4 of the
1959 IRE WESCON CONVENTION RECORD

A Parameter Tracking Servo for Adaptive Control Systems—M. Margolis and C. T. Leondes (p. 100)

This paper describes one very general approach to the design of adaptive control systems. The particular systems considered are process adaptive. The dynamic characteristics of the physical process are determined by the parameter tracking servo. The parameters thus determined are used to program the process' controller.

The parameter tracking servo is a closed loop self-adjusting system. It consists of the following elements; 1) the physical process, 2) the learning model, 3) the adjusting mechanism. The learning model and the physical process are subjected to the same input signals. Their outputs are compared and the resultant error is fed to the adjusting mechanism where some function of this error is used to adjust the parameters of the learning model.

The mechanism will continuously track the parameters of the physical process as they change with time in some unknown manner. The adjusting mechanism operates on an approximation to the method of steepest descent. These equations are derived for a first order process and the over-all system is analyzed. The equations describing the tracking servo's operation are both nonlinear and nonautonomous. System response as a function of input signal, gain, and error function are described analytically. Experimental results are included to demonstrate the validity of the analytic solutions.

Maximum Effort Control for Oscillatory Element—H. K. Knudsen (p. 112)

Maximum effort control is a method of achieving deadbeat response for a step input to an undamped second order element (two poles on the $j\omega$ axis of the s-plane) which is preceded by a saturating amplifier. This method of control supplies the maximum available energy to the element being controlled, by driving the amplifier to saturation whenever an error is present. The realization of a maximum effort control system for an oscillatory element is found through a phase plane analysis of the equations of motion of the oscillatory element. The control system topology is also found by the analysis of a phasor representation of the transients introduced in the oscillatory element by the output of the saturating amplifier.

The system was constructed to compare the experimental responses of step inputs and load disturbances, to the responses obtained from an idealized mathematical model of the system. The adaptability of the control system was tested by using it to control a damped oscillatory element.

The system described will be an aid in the design of the control system which will give optimum response for random inputs to an undamped second order element which is preceded by a saturating amplifier. It also provides a method of control for systems in which it is impossible to damp poles near the $j\omega$ axis.

Identification and Command Problems in Adaptive Systems—E. Mishkin and R. A. Haddad (p. 121)

In order to satisfy stringent performance requirements in a dynamic process, a computer is incorporated as a central element in the feedback loop. The computer performs the dual task of identifying or measuring the process' dynamics, and thence generating an appropriate command or actuating signal so as to satisfy the over-all specifications. The family of singularity functions (steps, ramps, confluent parabolas) is used as the command signal. The process' dynamics are monitored and identified by the computer without recourse to interrupting test signals such as periodic impulses or white noise. The stored energy term inherent in many measurement problems in continuous processes is accounted for in a novel manner.

Evaluating Residues and Coefficients in High Order Poles—D. Hazony and J. Riley (p. 132)

The powerful Laplace transform method for transient analysis by the partial fraction expansion technique has become quite popular in the fields of circuit and servo design. The theory of residues is usually used to find the coefficients of these fractions. The process is quite simple until second and higher order poles are included in the denominator. Previously, this has required a return to the calculus to find the additional coefficients required.

This paper discloses a simple technique for finding these additional coefficients by algebraic processes. As a result both manual and machine computation can be performed more easily. The technique is described and its mathematical basis is rigorously proven.

Coherent Optical Data Processing—L. J. Cutrona, E. N. Leith and L. J. Porcello (p. 137)

Coherent optical systems, which utilize the wave nature of light and the consequent diffraction phenomena, may often be used to supplement or even replace complex electronic equipment. Such systems are particularly adapted to the performance of certain linear mathematical operations, particularly those of an integral transform nature such as spectral analysis, convolution, auto- and cross-correlation, and matched filtering. The two-dimensional nature of optical systems, contrasted with the inherent one-dimensional nature of an electronic channel, allows a great reduction in equipment complexity for certain classes of operations.

This paper discusses the theory behind optical channels and filters as outlined above, and also illustrates simple multi-channel optical systems which can carry out representative operations.

Pole Determinations with Complex-Zero Inputs—J. A. Brussolo (p. 150)

A method for the determination of the characteristic pole locations in simple systems and components is discussed. The techniques introduced are extended to include more complex systems. The method consists of applying a signal to the system from a "complex-zero-generator" and then observing the system output response on an oscillograph. The system pole locations are determined when the system output goes through a null, which occurs when the zeros generated by the "complex-zero-generator" cancel the system poles. Tests on experimental systems indicate that the pole locations can be determined accurately and rapidly for a wide variety of systems.

For testing purposes, a "complex-zero-generator" was built using two square-wave generators with a timed delay between them. This generator gives a signal which can contain complex zeros anywhere in the s-plane. This signal is then applied to a number of systems containing several different relative pole orientations. The system outputs, as photographed on the oscillograph, are studied to develop rules and procedures to determine the pole locations. The rules are then applied to a number of "unknown" systems in order to determine their applicability and a study is made of the errors and limitations involved.

The results indicate that the method described is readily applicable to many systems and that, in many instances, the pole locations are determined more accurately and more rapidly than can be done through the use of a steady-state frequency analysis.

Random Noise with Bias Signals in Nonlinear Devices—G. S. Axelby (p. 167)

A number of investigations have been made in recent years about the transmission of Gaussian noise through nonlinear devices. In many cases, simplification or approximations were needed to make analytical solutions possible, and only zero-average Gaussian input signals were used when the results were applied to feedback control systems.

This paper presents a different approach to the problem of noise transmission through nonlinear single-valued elements. Basically, amplitudes removed by nonlinear saturation or deadzones are replaced by impulses in the amplitude distribution functions of the output signals, and the resulting first and second moments of the output distribution are computed to yield the average and rms value of the output signal. The solution may be found by graphical or mathematical integration, a visual representation of the phenomenon is obtained, and input signals with any distributions having non-zero average values may be considered.

It is shown that there is an equivalent transmission function or describing function for the average value of the noise, another for the rms value, and that one is a function of the other. Examples of the functions are given and the simpler functions with zero-average values are compared to the results obtained by other methods.

Finally, the application of the noise describing functions to feedback control systems is discussed. Theoretical results are compared with those obtained from analog simulations.

Nongyroscopic Inertial Reference—J. J. Klein (p. 182)

The space stabilizing cpability of a servo controlled nonrotating inertial mass is analyzed and its drift rate performance compared with a high precision gyroscope. The results indicate that the nongyroscopic inertial reference and guidance system exceeds the performance of gyroscopic systems by several orders of magnitude. It is shown that a servo system materially contributes to the drift accuracy in the nongyroscopic system but not in the gyroscopic system. The navigation errors of the discussed scheme are directly proportional to the accelerometer errors and, therefore, are inherently smaller than in an equivalent gyroscopic system.

Sampled Data Design by Log Chain Diagrams—M. P. Pastel and G. J. Thaler (p. 192)

The bilinear transformation

$$z = (1 + w)/(1 - w)$$

converts a z-transform function $G(z)$ of a sampled-data system into a new function $G(w)$, called the w-transform function, which is a rational function in variable w. This bilinear transformation maps the unit circle on the z-plane onto the imaginary axis of the w-plane. Consequently, it is now possible to draw log magnitude and phase diagrams readily against a frequency scale of the open-loop w-transform function of a sampled-data system by use of asymptotic techniques. Then, by use of a Nichols chart and correlation information available from continuous systems, it is possible to predict the approximate time domain performance. Design by modification of the open-loop transfer function can be made on the diagram in the same manner as employed for continuous systems on the Bode diagram. The resulting w-transform can be converted to its equivalent Laplace transform. The ratio of this transform function and the original Laplace transform function of the system's equipment gives the required compensator. Remote s-plane poles may have to be added to have the compensator physically realizable. Restricting the modifying w-plane poles to lie between (0) and (-1) permits the compensator to be realizable as an RC network.

Broadcast and Television Receivers

Vol. BTR-5, No. 3, December, 1959

Editorial (p. 1)
PGBTR Administrative Committee (p. 2)

Papers Reprinted from Part 7 of the 1959 IRE National Convention Record

Audio Applications of a Sheet-Beam Deflection Tube—J. N. Van Scoyoc (p. 3)

A number of unusual audio circuits have been developed which make use of a sheet-beam tube, type 6AR8. The 6AR8 tube is a miniature double-plate sheet-beam tube which incorporates a pair of balanced deflectors to direct the electron beam to either of the two plates and a control grid to vary the intensity of the beam.

This tube may be connected as a variable gain push-pull amplifier by connecting the input signal between the two deflectors and taking the output differentially between the two plates. When the tube is connected in this manner the amplifier gain is determined by the control grid voltage and may be varied over an 80 db range with negligible distortion.

The applications of this circuit include expansion and compression circuits, remote control of gain and mixing circuits, improved A.V.C. circuits and phase inversion. A number of these circuit arrangements are given in some detail and other applications are outlined.

A Drift-Free Direct-Coupled Amplifier Utilizing a Clipper-RC Feedback Loop—J. N. Van Scoyoc and E. S. Gordon (p. 8)

A unique drift-free direct-coupled amplifier has been developed employing a clipper and an RC integrating circuit in a feedback loop for stability. Equations are developed and computed and experimental curves are given for amplitude and phase-shift response as a function of frequency showing an extremely sharp power drop-off at the low end.

An existing application of this type of amplifier in an instrument for automatic counting and sizing of aerosol particles is described, demonstrating wide dynamic range and other advantageous features of the amplifier. Other potential applications of the Direct-Coupled Clipper-RC amplifier are given such as those of random pulse rate measurement, low level dc amplification using only a single-pole single-throw (SPST) chopper, and low level dc amplification of up to 20 concurrent inputs using a single amplifier and a slow-speed rotary switch.

Finally, a practical general purpose vacuum tube circuit of this amplifier type which was developed is described, giving data on pertinent characteristics such as low zero-drift, low noise, and high output capability.

The Application of the Voltage Variable Semiconductor Capacitor in Automatic Sweep Circuits and Signal-Seeking Receivers—J. Black (p. 16)

The basic method of automatic frequency sweep by charging a voltage variable capacitor is presented and the advantages over mechanically driven tuning capacitors are discussed.

The principle is extended by using the receiver automatic gain and/or frequency control for sweep control and station tracking, and practical circuits are shown embodying the principle.

Applications in the AM and FM fields, such as domestic and car radio receivers and television sets, are proposed.

The limitations of present devices and their effect on the application field are discussed.

An Analysis of a Transistorized Class "B" Vertical Deflection System—Z. Wiencek and J. E. Bridges (p. 20)

Considerations in Transistor Automobile Receiver Front End Design—R. Martinengo (p. 31)

This paper discusses the requirements which must be considered in the design of an RF amplifier stage and converter for a transistor automobile receiver. Several coupling networks for the antenna and interstage circuits are discussed and performance data are given for various combinations of circuits. Data are given for a converter circuit including voltage and temperature effects on frequency stability.

A Five-Transistor Automobile Receiver Employing Drift Transistors—R. A. Santilli and C. F. Wheatley (p. 38)

Improvements in Detection, Gain-Control, and Audio-Driver Circuits of Transistorized Broadcast-Band Receivers—D. Thorne and R. V. Fournier (p. 46)

Application of Rotationally Non-Symmetrical Electron Lenses to TV Image Reproduction—D. W. Taylor, N. W. Parker and H. N. Frihart (p. 54)

Recent developments in the art have dictated the division of this paper into two component parts. The first deals with a quadrapolar, magnetic lens of rotational nonsymmetry used to achieve scan magnification with a television cathode ray tube. The second concerns the development of a negative, electrostatic, gauze lens exhibiting full rotational symmetry which is also used to provide scan magnification.

In the discussion, the quadrapole lens is synthesized from component fixed fields and the electron beam trajectories within the lens predicted. An analogy with crossed, positive and negative , cylinder lenses of light optics is expressed. The design of a complete, scan-magnified, image reproducing system is considered.

The theory of the rotationally symmetrical divergent lens is developed from an extension of the theory of bi-potential lenses. Problems of mesh scatter are treated and spot size increase due to mesh scatter is calculated. Other optical problems introduced by the mesh are discussed.

A High Sensitivity Ultrasonic Microphone—P. Desmares and R. Adler (p. 64)

Papers Reprinted from Parts 2 and 7 of the 1959 IRE WESCON Convention Record

The FM Multiplex Stereo Receiver—H. N. Parker (p. 70)

Circuit Aspects of Parametric Amplifiers—H. Seidel and G. F. Hermann (p. 75)

Parametric amplifiers are distinguished from most active networks in that power is taken directly from an ac source and that the phase of this source is significant in the amplification process. As a consequence of the harmonic spectrum produced by the interaction of the power source (pump) and the nonlinear element, the introduction of a small signal generates a pair of sidebands about each harmonic. Networks with variable parameters may be handled with an extension of the conventional formalism into one of frequency as well as spatial scattering.

We deal with two cases. In the first we consider the lower sideband amplifier which requires only a two frequency dscription; the signal and the lower sideband. Such a system may be optimized by adding equalizing networks whose synthesis stems from passive network procedures.

The second case considers a periodic cascade in which the pump phase is assumed to be varying uniformly. The nature of the natural modes of such a system are derived from general considerations of time and space symmetry. The reactive case is considered specially and orthogonality relations are produced which resemble those of a conventional network chain.

Four Terminal Equivalent Circuits of Parametric Diodes—C. S. Kim (p. 83)

Four terminal equivalent circuits of variable capacitance (parametric) diodes used in various configurations of converters and amplifiers are presented. These equivalent circuits are derived from small signal approximations for the nonlinear dynamic capacitance of a diode. The cases considered involve three frequencies, namely input and output signal frequencies and pumping frequency for converters or input signal frequency, idler and pumping frequencies for amplifiers.

These four terminal equivalent circuits are analogous to those for transistors and vacuum tubes. They help to give an understanding of parametric operation and may be used to obtain expressions for gain, bandwidth and noise figure.

Circuit Theory

Vol. CT-7, No. 1, March, 1960

Iterative Traveling-Wave Parametric Amplifiers—C. V. Bell and G. Wade (p. 4)

It is well known that the parametric principle can give low-noise amplification at microwave frequencies. The conventional parametric amplifier involves a single variable element and one or more resonant cavities. Such an amplifier is extremely narrow band, it suffers from large changes in gain due to small changes in pump level, and it must be used with a circulator if unilateral gain is desired. These difficulties can be overcome by using a number of variable elements in a traveling-wave circuit.

This paper presents the circuit considerations appropriate to wideband operation in a traveling-wave parametric amplifier. The model which is analyzed is a transmission line periodically loaded with parametric diodes. The diodes constitute the variable elements. Across each diode is fed a large pumping voltage which produces a time-varying capacitance.

A Brillouin diagram for the structure (*i.e.*, a plot of ω vs β) can be computed from the analysis. The conditions for high gain, wide band, and other desirable characteristics are conveniently determined from this diagram.

On the Application of the Base Charge Concepts in the Design of Switching Circuits—R. S. C. Cobbold (p. 12)

This paper described a new method of measuring the effective decay time of excess minority carriers in the base of junction transistors, the results of which show an approximately exponential decay with time. The relation between the decay-time constant and the normal and inverse transistor parameters is discussed, and it is shown how the experimental measurements can be directly applied to the design of transistor pulse circuits.

Using the Ebers and Moll equivalent circuit for a saturated transistor, an analysis is made of the effect on the charge storage caused by the passage of a collector current when the base connection is open circuit. The case of a transient collector current is also examined, and it is concluded that for typical alloy junction transistors the passage of a collector current plays little part in determining the charge storage. Thus, the storage time with open-circuit base is determined by the initial excess charge, the collector current existing when the transistor enters the active region, and the decay time constant for minority carriers. A simple equivalent circuit for determining the decay of stored charge when a reverse base current is applied is also discussed.

Element Coefficients for Symmetrical Two-Section Filters Having Tchebycheff Response in Both Pass and Stop Bands—D. C. Pawsey (p. 19)

Elements coefficient for a normalized symmetrical low-pass filter, having "equal ripple" response in both pass and stop bands, are presented graphically. The coefficients are plotted against the relative selectivity of the filter, with a loss factor as independent parameter. The interval between curves is sufficiently small to permit interpolation with an accuracy of ±1 per cent.

Frequency and impedance transformations are included to allow the elements of a practical filter to be derived from those of the appropriate normalized design.

The loss function corresponding to a particular design is readily formulated in terms of the Loss factor above and the appropriate frequencies of zero loss.

Maximum Gain Realization of an RC Ladder Network—A. Paige and E. S. Kuh (p. 32)

This paper is concerned with the synthesis of the voltage transfer function of an unterminated RC ladder network. Given

$$A(p) = \frac{V_2}{V_1} = K\frac{N(p)}{D(p)},$$

the constraint on N and D is well known and the realization procedure is straightforward. However, for many applications, it is important to realize the maximum possible gain (K max) associated with a given transfer function. This paper presents a method of determining $K_{\max}$ from the given $A(p)$. Furthermore, it is shown that if the maximum gain occurs at dc or at infinite frequency, $K_{\max}$ can be realized exactly. If the maximum gain occurs at a finite frequency, $K_{\max}$ can be approached arbitrarily closely.

On Coefficients of Polynomials in Network Functions—S. L. Hakimi and W. Mayeda (p. 40)

This paper presents a study of the relationships between the missing powers of polynomials in network functions and the network geometry. The elementary transformation of trees and the 2-trees of a network are introduced to obtain the necessary and sufficient conditions for polynomials in network functions to have missing powers. It is shown that the polynomial in the numerator of the transfer function of a grounded two-terminal-pair RLC network cannot have two successive missing powers unless some common factors of the numerator and the denominator are cancelled. This result is useful in topological synthesis where one must usually restore all the necessary surplus factors before deciding on the minimum number of vertices and the geometry of the network.

A General Class of Maximally-Flat Amplitude Response Ladders—Sid Deutsch (p. 45)

It is shown that the elliptical Tchebycheff pole array defines a general class of maximally-flat amplitude functions when the number of poles approaches infinity. The infinite-order pole array can be realized as an infinite cascade of identical two-terminal ladders. The amplitude characteristic of the driving-point impedance of the two-terminal ladder is flat up to the nominal cutoff frequency, ω_0. Beyond ω_0, the exact shape of the amplitude characteristic is determined by the eccentricity of the original pole array. The two-terminal ladder is a low-pass R, L, and C structure that is infinitely long. Two special cases are considered: 1) when the pole array becomes linear, the ladder is a constant-k type; 2) when the pole array becomes circular, the shunt conductances and series resistances of the ladder rapidly taper toward zero while its C and L components taper toward a constant-k type.

Optimum Estimation of Impulse Response in the Presence of Noise—Morris J. Levin (p. 50)

The problem considered is that of estimating the impulse response of a linear system from records of its input and output during a limited interval of time when the system output is obscured by additive random noise. Standard results from statistical estimation theory are applied to derive least squares and Markov estimates which are optimum in the sense of having minimum variance among all linear unbiased estimates. No special assumptions are required concerning the form of the input. Expressions for the variances of the sampling errors are given. The relationships of these estimates to other methods of estimation which have been suggested are discussed.

Demodulated Lead Networks—Erik V. Bohn (p. 56)

One of the possible types of compensating networks for carrier-frequency servo systems is the demodulator lead network. By means of synchronous switching, a nonlinear operation is performed on the envelope of the input. For the case of very high carrier-to-signal-frequency ratio, an equivalent linear circuit is derived which is that of a typical dc lead network. The response to a step input in conjunction with quasistationary Fourier analysis and description of function methods is used to derive the circuit elements. The equivalent circuit is verified experimentally and its range of validity discussed.

Regenerative Modes of Active Networks—E. S. Kuh (p. 62)

An active device with passive imbedding can produce natural frequencies in the right-half plane. In the design of regenerative circuits, it is important to find the permissible location of regenerative modes. In this paper the maximum real part of the natural frequency of an active device under arbitrary passive imbedding is determined. Furthermore, it is shown that this regenerative mode can actually be realized. For the case of a pentode, the required passive network is a gyrator.

Reviews of Current Literature (p. 64)

Correspondence (p. 67)

Electron Devices

Vol. ED-7, No. 1, January, 1960

Tunnel Diodes—R. N. Hall (p. 1)

This paper presents a review of the properties, principles of operation, and implications of the tunnel diode. Following a brief description of the unusual characteristics of this device, a discussion is given of the mechanism which leads to the negative resistance. Experiments showing the transition from the tunnel diode characteristic to that of a high-voltage avalanche diode are exhibited. The electrical characteristics of tunnel diodes are outlined making use of the small-signal equivalent circuit which represents the behavior in the negative resistance region. Diodes designed for high-frequency operation are described and examples are given of circuits which demonstrate their behavior as switches, radio receivers, and microwave oscillators. In connection with a discussion of the temperature dependence of these devices, experiments are described which demonstrate the importance of phonons in determining their characteristics at the temperature of liquid helium.

Prediction of Storage Time in Junction Transistors—R. P. Nanavati (p. 9)

This paper points out that in the prediction of storage time one needs to know only a single fundamental device parameter, the storage time constant T_s. Several methods of measuring T_s are considered and compared both theoretically and experimentally. A single nonoscilloscope method of measuring T_s is discussed and its theory presented. This method holds out the best promise for the ability to predict the storage time of very fast transistors. It is therefore now possible to predict large signal transient response of transistors on the basis of small signal nonoscilloscope measurements.

One-Dimensional Traveling-Wave Tube Analyses and the Effect of Radial Electric Field Variations—J. E. Rowe (p. 16)

The equivalence of the differential-equation and integral-equation approaches to the solution of the nonlinear traveling-wave amplifier problem is shown rigorously. The equations can be transformed one into the other without making any additional assumptions. The space-charge expression developed on the basis of considering the electron distribution in phase space is shown to give the same form for the space-charge weighting function as a space-charge expression based on the electron distribution in space. Efficiency calculations are compared for the two methods and the agreement is excellent. Corrections to earlier calculations are included. The effect of radial electric field variations due to the circuit is considered and it is shown that the efficiency for large streams is reduced in direct proportion to the square of the field reduction function.

Small-Signal Analysis of the Helitron Oscillator—Richard H. Pantell (p. 22)

In this paper, a small-signal analysis of a microwave oscillator, discussed by Watkins and Wada is presented. This tube, the helitron, has an electron beam describing the trajectory of a helix between two concentric cylinders. Interaction is with a TEM mode supported on the inner cylinder, and the beam is focused by having a potential difference between the cylinders. This has been termed an E-type tube.

The E-type tube had originally been conceived as a device for exchanging electron potential energy of an electrostatically focused beam for RF energy. In this manner, one would expect to obtain the high efficiencies associated with an M-type tube, without requiring a magnetic field.

Watkins and Wada presented experimental results in their paper, and they indicated that the theory that had been developed did not predict the observed behavior. In particular, it was stated that if the propagation constants were those of an M-type tube, the measured starting current would be one-fiftieth of the theoretical starting current.

The small-signal analysis of the E-type tube developed in the main body of this paper has yielded two interesting results:

1) The electrons bunch along the direction of rotation, and lose kinetic energy. In this sense the E-type tube behaves similar to the O-type oscillator. Electron motion transverse to the dc path, which is important in the M-type tube, is not important for E-type operation.

2) Space charge forces tend to increase the bunching along the direction of rotation. This results in a negative value for the space-charge parameter, and an attendant reduction in starting current. Growing waves can exist on an electron beam that is electrostatically focused between two conducting cylinders, even without the presence of a circuit field. In this sense the E-type oscillator is similar to the M-type tube.

Generation-Recombination Noise in Semiconductors—The Equivalent Circuit Approach—Keith S. Champlin (p. 29)

Generation-recombination noise in semiconductors in thermal equilibrium is treated from the standpoint of thermal fluctuations in equivalent electrical circuits. For the general volume recombination model, a method based on network reduction is presented which allows one to calculate the spectral density of the electron and hole fluctuations without solving for the spectra of the fluctuations in occupancy of the recombination centers and traps. The method is extended to a surface recombination model, thereby avoiding the ambiguities found in previous formal treatments. It is shown that the concept of ambipolar diffusion, the location and spectral density of the random sources, and the spatial correlation of Fourier coefficients of carrier density fluctuations all have simple significance in electrical terms.

Using transmission line techniques, the generation-recombination (GR) spectrum is calculated for a two-level semiconductor where recombination occurs at opposite plane surfaces. This new result is examined in detail for the limiting cases approached when the recombination process is 1) volume-limited, 2) surface-limited, and 3) diffusion-limited. It is shown that, in the first two cases, the spectrum is identical with that obtained from a zero-dimensional analysis provided the time constant is properly defined. For the diffusion-limited case, however, the spectrum varies as $1/\omega^{3/2}$ at high frequencies, and at low frequencies the noise is 5/6 that predicted by the simple theory. The new result is shown to compare favorably with measurements reported previously by Hill and van Vliet.

Comparison of *N-P-N* Transistors and *N-P-N-P* Devices as Twenty-Ampere Switches—H. W. Henkels and F. S. Stein (p. 39)

A series of 20-ampere silicon *n-p-n* transistors and three-terminal *n-p-n-p* switches have been developed, and their characteristics are compared with respect to high-current switching applications. At the present time, collector-emitter voltages of the transistors are generally lower than those of the switches, which may exceed 400 volts. The *n-p-n* transistors are somewhat simpler to produce than the *n-p-n-p* structures. However, the ultimate current-handling capacity of the latter type of device is greater, because of the uniform current density. The saturation voltage drops at 20 amperes are comparable, being in the order of one to two volts. The switch has a distinct advantage in the turn-on speed, while the transistor has the equally important advantage that the base retains control for turn-off.

Triode Electron Injection Systems for Hollow Beams—L. A. Harris (p. 46)

Novel electron guns, in which a conical hollow electron beam is projected at a large angle to the axis into a coaxial deflection region, were tested. The guns have a triode structure so that the perveance can be varied easily. The strong deflection increases the effective perveance of the beam and makes the trajectories insensitive to current variations. In the form of a device with the gun at a large radius and projecting the beam inward, the electron paths are sensitive to scattering in the gun. The inverted gun, projecting the beam outward, is relatively free from this difficulty. The systems generally behave as expected, and should be quite useful for initiating variable-current hollow electron beams in various available focusing arrangements.

A New Concept in Microwave Gas Switching Elements—Ray S. Braden (p. 54)

A gas switching tube commonly known as a TR tube is an RF energy switch, the operation of which is a function of incident power level. Switch operation is achieved by gaseous ionization. The major problem in the design of gas switching devices has been that of achieving, simultaneously, a short recovery time and a low arc loss. This problem has been eliminated by the development of the device described in this paper. The design objective was to produce a self-contained TR window for operation at very high powers. The arc loss developed by conventional tube design at these high power levels would be sufficient to melt any known window material. The design of this device is such that the ionizable gas blanket takes the form of a thin-walled cylinder suspended in the iris in a dielectric cylinder. This configuration presents a smaller volume of gas with a reduced cross section and a much shorter diffusion length. These changes result in lower leakage power, faster recovery time, and reduced arc loss.

As finally developed, the window does not involve glass-to-metal or ceramic-to-metal seals. The problem of metal sputtering or outgassing is therefore eliminated. By a unique spring pressure support, the problem of strain developed by differences of thermal coefficients of expansion is eliminated. The open-ended design of the cylinder provides excellent facilities for cooling the window.

Prototype units have been successfully operated in *L* band at power levels considerably in excess of 15 mw peak power and 30 kw average power. These units exhibited recovery times of 5 to 20 μsec with high-level attenuation of 26 to 35 db and arc loss below the level of present measuring techniques, *i.e.*, <0.02 db.

A practical window for these high powers with a loaded *Q* of less than 1.5 has been fabricated.

Transistor Behavior at High Frequencies—R. P. Abraham (p. 59)

The tee equivalent circuit for junction transistors has been modified to take account of electric field in the base region. This electric field is the result of a graded impurity density in the base region of the transistor. It is shown that a graded base improves the high-frequency performances of the common base stage; however, the improvement in common emitter performance is considerably less because of the increased "excess" phase which accompanies the improved high-frequency performance. The complex hybrid parameters are calculated for the common base and common emitter configurations; these calculations take into account the parasitic interterminal capacities of the transistor. The common emitter calculations are compared to measure data, and substantial agreement is obtained.

Contributors (p. 70)

Engineering Management

Vol. EM-7, No. 1, March, 1960

Editorial (p. 1)

A Stochastic Model for Determining the Size and Allocations of the Research Budget—Raoul J. Freeman (p. 2)

An analytical method is presented for determining the size of the research budget and allocating it among competing projects. A stochastic model is utilized. The over-all profit-maximization of the firm is used as a framework. A hypothetical example is given to illustrate the method.

Regression Models for Company Expenditures on and Returns from Research and Development—Ira Horowitz (p. 8)

Data were gathered on the research expenditures, sales, and profits of a sample of large firms which had been conducting organized research for 25 years or more. A linear relationship is hypothesized for explaining the size of the research budget. Several factors influencing the size of the research budget are examined. A regression model is developed for expressing the returns on R & D expenditures with lags up to six years. Suggestions are made for the application and possible uses of the method by an individual firm.

Intracompany Systems Management—Harry H. Goode (p. 14)

Research and Development on complex systems requires experimentation with the organizational form of the technical effort. Three levels of system design are distinguished—the set, the set of sets, and the set of sets of sets. The evolution of complex system design is described. Five organizational modes are examined and evaluated. The crossbar mode is suggested as best for large scale system projects and is described in detail.

Enculturation in Industrial Research—Robert W. Avery (p. 20)

The new researcher undergoes a learning experience in the laboratory, in which he attempts to relate his technical competence to the needs of his employer. More than one hundred members of ten industrial laboratories were interviewed in order to discover the kinds of things the new researcher learns, the problems he encounters, etc., as he first adapts himself to the milieu of the industrial laboratory. Emphasis is placed in the analysis of these data on the factors influencing the kinds of ideas he produces and how he handles ideas.

Some Organizational Factors Affecting Creativity—Norman Kaplan (p. 24)

Until recently, theoretical discussions and careful conceptual analyses have been rare in the literature on creativity. Studies of the organizational and environmental factors affecting the creativity of scientists have also been rare, but are becoming more common. This paper reports on the factors considered important in influencing creativity in a number of research laboratories. The data were gathered through interviews with research directors, administrators, and scientists. Five factors are identified and analyzed.

Role Concept of Engineering Managers—Simon Marcson (p. 30)

This paper contains preliminary results of a questionnaire survey among engineering managers in a large electronics company. Engineering managers are divided into three levels and compared with respect to their degree of business and professional orientation, their conception of authority, and their understanding of the problems of nonsupervisory engineers.

On the Anatomy of Development Projects—Peter V. Norden (p. 34)

The structure of an R & D project is described in terms of an Effort-Distribution Array. A logistic model is presented for the cumulative times series of effort devoted to a project, and problems of using such curves for prediction are discussed. A set of rules is given, which, with the aid of computer simulation, can be used to generate a project schedule. The consequences of several combinations of rules and restrictions are examined.

Human Factors in Electronics

Vol. HFE-1, No. 1, March, 1960

Frontispiece and Editorial—Curtis M. Jansky (p. 2)

Man-Computer Symbiosis—J. C. R. Licklider (p. 4)

Man computer symbiosis is an expected development in cooperative interaction between men and electronic computers. It will involve very close coupling between the human and the electronic members of the partnership. The main aims are 1) to let computers facilitate formulative thinking, as they now facilitate the solution of formulated problems, and 2) to enable men and computers to cooperate in making decisions and controlling complex situations without inflexible dependence on predetermined programs. In the anticipated symbiotic partnership, men will set the goals, formulate the hypotheses, determine the criteria, and perform the evaluations. Computing machines will do the routinizable work that must be done to prepare the way for insights and decisions in technical and scientific thinking. Preliminary analyses indicate that the symbiotic partnership will perform intellectual operations much more effectively than man alone can perform them. Prerequisites for the achievement of the effective, cooperative association include developments in computer time sharing, in memory components, in memory organization, in programming languages, and in input and output equipment.

Pattern Recognition and Display Characteristics—W. R. Bush, V. M. Donahue and R. B. Kelly (p. 11)

This paper reports experimental results of human operator performance in a visual recognition task. The work began with a method of generating families of complex patterns to simulate certain characteristics of visual sensor displays, such as radar and infrared returns. The experimental effort was directed toward establishing criteria for predicting human operator performance in a map-matching task. The operators' task was to recognize which of four patterns presented simultaneously with a reference pattern belonged to the reference pattern family. The measure of performance was the time in seconds taken by the operator to make a selection. Response times were more rapid when the reference pattern was less complex than the comparison than when the reference pattern was the more complex. Analysis of the display characteristics led to the selection of four physical measures to be used in predicting operator performance. These measures—pattern length, pattern density, and two measures of pattern complexity—correlated highly with response time, were not highly intercorrelated, and were applicable to natural sensor returns. The four measures were found to account for a high degree of the total variance. Regression equations were derived which predict performance from known values of the four measures.

The Use of Quickening in One Coordinate of a Two-Dimensional Tracking System—J. W. Duey and R. Chernikoff (p. 21)

In a previous study, it was found that tracking error in one coordinate of a two-dimensional tracking system was affected by the dynamics used in the other coordinate. In particular, tracking performance progressively deteriorated as the dynamics in the two coordinates become more dissimilar. The present study seeks to extend these findings by determining how the introduction of quickening into one coordinate of a second-order, two-coordinate tracking system would affect the performance in the unquickened coordinate. In the light of the previous study, it might be expected that quickening one coordinate would degrade the performance of the other. On the other hand, the simplification of the tracker's task induced by quickening might effect an improvement in performance.

The findings suggest that a counterbalance of the above factors was achieved, since quickening one coordinate had no effect on performance in the other.

Desirable Push-Button Characteristics—Richard L. Deininger (p. 24)

This paper reports the results of studies in a series concerning the characteristics of push-button keysets that people can operate quickly, accurately and conveniently. The studies investigated push-button arrangements, button top and lettering characteristics, and push-button force-displacement characteristics. Considerable latitude exists in the design of keysets if only keying performance is considered. The preference judgments were somewhat more selective, particularly for the force-displacement characteristics of the button mechanism.

The Relation of Electronic and Optical Gain to System Performance—S. Seidenstein and H. P. Birmingham (p. 30)

An experiment was conducted to investigate the effect of adjusting display gain upon man-machine system performance in a simple aided tracking system. Gain was varied in two ways: electrically by changing amplification, and optically by changing the distance from the scope to the eye. Manipulation of gain by each method produced similar changes in system performance. Over the ranges studied, system error decreased as display gain was increased. This result agrees with predictions based upon closed-loop control system theory and suggests the feasibility of including additional experimental variables within the theory.

Communications (p. 33)

Reviews of Current Literature (p. 35)

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Industrial Electronics

PGIE-11, December, 1959

New Developments in Stream Analysis—V. H. Adams and D. J. Fraade (p. 1)

Nuclear Magnetic Resonance Applications—Herbert Rubin (p. 9)

Use of Infrared Techniques in Industrial Instrumentation—H. L. Berman and G. F. Warnke (p. 15)

Nondestructive Eddy Current Testing—Glenn O. McClurg (p. 20)

Electronic Photography—M. L. Sugarman, Jr., M. B. Levine and N. P. Steiner (p. 26)

Applying Military Reliability Research to Industrial Electronics—H. L. Wuerffel (p. 34)

Digital Control Systems—Present and Future—Montgomery Phister, Jr. (p. 44)

New Magnetic Recording Techniques for Data Processing—Marvin E. Anderson (p. 47)

Some Aspects of Magnetic Recording Useful for Industrial Control—Edward G. Wildanger (p. 53)

Recent Developments in Transducer Technology—Y. T. Li (p. 57)

Microwave Theory and Techniques

Vol. MTT-8, No. 1, January, 1960

A Message from the Editor—Donald D. King (p. 2)

Microwave Price (p. 3)

Theoretical Limitations to Ferromagnetic Parametric Amplifier Performance—R. W. Damon and J. R. Eshbach (p. 4)

It has been commonly expected that improved operation of the ferrite parametric amplifier could be obtained by use of materials of narrower resonance linewidth, ΔH. This parameter is critical in determining the pumping power (P_p) required for operation of the device. Also of importance, however, is the limitation of device properties determined by the dependence on ΔH of the instability threshold of the spin-wave system. Considering this limitation, the maximum voltage gain-fractional bandwidth product ($g_v\Delta\omega/\omega_1$) has been determined as a function of other device parameters, and typical values calculated for several modes of operation. In the electromagnetic mode, for example, there is an optimum ΔH which yields maximum $g_v\Delta\omega/\omega_1$ at a given pumping power. It is also shown that a minimum filling factor, also a function of ΔH for some types of operation, is required to reach the oscillation threshold even in the unloaded device.

An Extension of the Mode Theory to Periodically Distributed Parametric Amplifiers with Losses—K. Kurokawa and J. Hamasaki (p. 10)

For the extension of the mode theory of the lossless periodically distributed parametric amplifier to the lossy case, a "conjugate circuit" is introduced in this paper. The conjugate circuit is an imaginary circuit which is obtained in the passband by replacing each resistance in the original circuit with the negative resistance of the same magnitude. The orthogonality properties between the modes of the original circuit and those of the conjugate circuit are derived. The power gain and the noise figure of the amplifier are calculated, showing the usefulness of this mode theory in accounting for the spreading resistance of the semiconductor diode.

Action of a Progressive Disturbance on a Guided Electromagnetic Wave—J. C. Simon (p. 18)

Periodic and Guiding Structures at Microwave Frequencies—A. F. Harvey (p. 30)

The paper reviews the properties of periodic and guiding structures which now play an important part in the operation of components, antennas, electron tubes and low-noise amplifiers. An account is first given of dispersive propagation in periodic-loaded lines, showing how the frequency characteristic breaks into pass and stop bands. The formation of forward- and backward-space harmonics and the effects of systematic modification of loading are examined. A description is then given of the various types of surface-wave structures including dielectric rods, dielectric-clad metals, and corrugated surfaces, as well as surface wave instruments and circuits. Practical slow-wave structures such as ladder lines, coupled cavities and helices are finally treated. The survey concludes with a bibliography.

Design of Mode Transducers—L. Solymar and C. C. Eaglesfield (p. 61)

The propagation of the electromagnetic wave in a gradual transducer is discussed. It is shown that the incident mode and the geometry of the transducer determine the outgoing mode. Inverting this theorem, a method is suggested for the design of the transducer's surface for cases in which the desired modes in the uniform waveguides are given.

The application of the method is illustrated in three examples.

UHF Resonator with Linear Tuning—B. H. Wadia and R. L. Sarda (p. 66)

A novel method of tuning a transmission-line type resonator is described. The first-order theory of such a resonator is derived and presented in the form of design curves which indicate an extremely good tuning linearity. Experiments with a resonator designed on this principle agree with theory.

Equivalent Circuits for Small Symmetrical Longitudinal Apertures and Obstacles—Arthur A. Oliner (p. 72)

Formulas based on small aperture and small obstacle theory are presented for the determination of equivalent circuits for symmetrical longitudinal apertures and obstacles. These formulas are then applied to several examples of practical interest, including aperture discontinuities in trough waveguide and an obstacle array of interest to anisotropic radomes.

On the TE$_{n0}$ Modes of a Ferrite Slab Loaded Rectangular Waveguide and the Associated Thermodynamic Paradox—A. D. Bresler (p. 81)

It has been known for some time that the secular equation for the TE$_{n0}$ modes of a perfectly conducting rectangular waveguide loaded with a transversely magnetized dissipationless full height ferrite slab located against one of the narrow walls of the waveguide admits the possibility of the existence of only a single propagating mode (transporting energy in one direction only). In this paper, it is established that if we admit the existence of a passive dissipationless uniform waveguide supporting only a single propagating mode we are led inescapably to a thermodynamic paradox. A uniqueness theorem is cited to establish that, for the waveguide described above, the paradox is associated with the TE$_{n0}$ mode set alone. This conclusion motivates a thorough study of the secular equation for the TE$_{n0}$ modes of this waveguide. This study is initiated by an investigation into the properties of the TE$_{n0}$ surface waves guided along a plane interface separating a transversely magnetized dissipationless ferrite from free space. It is shown that two oppositely directed surface waves are guided along this interface. These two surface waves are admitted in different finite ranges of the parameter values which never coincide and which may or may not overlap. Each of the two surface waves has both a high- and a low-frequency cutoff and, in general, both a high and a low dc magnetic field cutoff. The propagation constant of one of the surface waves becomes infinite at the low field (high-frequency) cutoff. The next step in the analysis consists of an examination of the behavior of these surface waves on finite thickness ferrite slabs located in different environments. It is shown that when one of the two interfaces bounding the slab approaches a short circuit the infinite propagation constant noted above behaves in a peculiar discontinuous fashion. Next, the TE$_{n0}$ mode secular equation of the slab loaded rectangular waveguide is analyzed and information is developed leading to a description of the behavior of the propagation constants of all the propagating TE$_{n0}$ modes. This analysis reveals that the possibility of the existence of only a single propagating mode is associated only with the surface wave mode of this waveguide. A resolution for the thermodynamic paradox is proposed based on the discontinuous behavior of one of the infinite propagation constants associated with this surface wave mode. It is shown that with a properly chosen secular equation for the waveguide under consideration there are always an even number of TE$_{n0}$ propagating modes, half of which transport energy in one direction, half in the other. This demonstration is based, in part, on an analysis leading to relations between the direction of the power flow associated with a propagating mode and the derivative of its propagation constant with respect to the dc magnetic field.

***L*-Band Ferromagnetic Resonance Experiments at High Peak Power Levels**—E. Schlomann, J. Saunders, and M. Sirvetz (p. 96)

Ferromagnetic resonance absorption at high peak power levels has been observed at 1300 mc in yttrium-gadolinium garnets and in a nickel ferrite-aluminate. In agreement with theoretical predictions, the critical field characterizing the onset of nonlinear effects, in a series of yttrium-gadolinium garnet disks of a given shape, was found to be very sensitively dependent on the gadolinium content. Similarly, for samples of a given composition, the critical field strength was sensitively dependent on the shape of the sample in agreement with theoretical predictions. At moderate power levels the susceptibility varies linearly with the square of the RF magnetic field strength over an appreciable range. This result can be understood in terms of an extension of Suhl's theory. The results can be used to predict the high power performance of these materials when used in isolators.

High Power Ferromagnetic Resonance at *X*-Band in Polycrystalline Garnets and Ferrites—J. J. Green and E. Schlomann (p. 100)

Resonance experiments have been performed at *X*-band on spherical samples of polycrystalline yttrium garnet, yttrium-gadolinium garnet, yttrium-holmium garnet and nickel-cobalt ferrite. The RF field strength extended up to 60 Oersted. In the case of yttrium garnet the samples differed considerably in density and hence in linewidth. At fairly low power levels the susceptibility at resonance varies linearly with the square of the RF magnetic field strength. At high power levels the susceptibility is inversely proportional to the amplitude of the microwave magnetic field. The "spin-wave linewidth" ΔH_k is inferred by extrapolation from the behavior at very high powers. It is found that ΔH_k is, to a large extent, independent of the linewidth ΔH observed by the usual low power experiments. In particular ΔH_k was found to be essentially the same (approximately 4 Oe) for all yttrium iron garnets (single crystals and polycrystals with linewidth varying between 1.8 Oe and 450 Oe). On the other hand, ΔH_k increases very rapidly if the yttrium is partially substituted by holmium ($\Delta H_k \sim 11$ Oe for 1 per cent substitution).

Microwave Diode Cartridge Impedance—R. V. Garver and J. A. Rosado (p. 104)

In any application of a semiconductor microwave diode, the impedance of the diode cartridge plays a very important role. Two commonly made assumptions, which are quite erroneous, are that 1) the impedance of the diode cartridge consists simply of a shunt capacitance and whisker inductance, and 2) the metal-to-semiconductor junction at microwave frequencies behaves approximately as it does at 10 mc. In this paper it is shown that the impedance of the diode cartridge at microwave frequencies can be measured accurately by substituting a carbon die for the semiconductor.

Theory of the Germanium Diode Microwave Switch—R. V. Garver, J. A. Rosado and E. F. Turner (p. 108)

The application of a generally neglected theory of microwave detection to the poorly understood problem of metal-to-semiconductor junction behavior at microwave frequencies is discussed. Experimental results are disclosed which support the theory and appear to be the first experimental verification of it. It is shown how the theory predicts that germanium microwave diodes should exercise direct switching action upon microwaves while silicon microwave diodes should not, as had been observed in the past but with no explanation.

Improvement in the Square Law Operation of 1N23B Crystals From 2 to 11 KMC—A. Staniforth and J. H. Craven (p. 111)

Crystal rectifiers have been used for many years as video detectors in microwave measurements. In most of the applications the detection characteristic at low level is assumed to be square law. It is well known that, in general, this assumption is not justified, particularly if reasonable accuracy is desired. The conditions required to increase the dynamic range over which square law response may be achieved have been investigated experimentally. Results obtained in this laboratory have indicated that a forward bias current of 100 microamperes or more with a low video load resistance made the operation of the crystal closer to the ideal square law over a larger dynamic range.

An *N*-Way Hybrid Power Divider—Ernest J. Wilkenson (p. 116)

A circularly symmetric power divider is described which splits a signal into *n* equiphase equiamplitude parts where *n* can be odd or even. The power divider provides isolation between output terminals and approximately matched terminal impedances over about a 20 per cent band. A theory of operation is given which yields the necessary design parameters, and an experimental model is described which has a minimum isolation of -27 db between output terminals, an output VSWR of 1.6, and an input VSWR of 1.2.

Correspondence (p. 119)

Abstracts and References

Compiled by the Radio Research Organization of the Department of Scientific and Industrial Research, London, England, and Published by Arrangement with that Department and the *Electronic Technology* (incorporating *Wireless Engineer* and *Electronic and Radio Engineer*) London, England

NOTE: The Institute of Radio Engineers does not have available copies of the publications mentioned in these pages, nor does it have reprints of the articles abstracted. Correspondence regarding these articles and requests for their procurement should be addressed to the individual publications, not to the IRE.

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The number in heavy type at the upper left of each Abstract is its Universal Decimal Classification number. The number in heavy type at the top right is the serial number of the Abstract. DC numbers marked with a dagger (†) must be regarded as provisional.

UDC NUMBERS

Certain changes and extensions in UDC numbers, as published in PE Notes up to and including PE 666, will be introduced in this and subsequent issues. The main changes are:

Artificial satellites:	551.507.362.2	(PE 657)
Semiconductor devices:	621.382	(PE 657)
Velocity-control tubes, klystrons, etc.:	621.385.6	(PE 634)
Quality of received signal, propagation conditions, etc.:	621.391.8	(PE 651)
Color television:	621.397.132	(PE 650)

The "Extensions and Corrections to the UDC," Ser. 3, No. 6, August, 1959, contains details of PE Notes 598–658. This and other UDC publications, including individual PE Notes, are obtainable from The International Federation for Documentation. Willem Witsenplein 6, The Hague, Netherlands, or from The British Standards Institution, 2 Park Street, London, W.1., England.

ACOUSTICS AND AUDIO FREQUENCIES

534.2 **1084**
On Waveguide Sound Propagation in Layered Inhomogeneous Media—E. P. Masterov. (*Akust. Z.*, vol. 5, no. 3, pp. 332–336; 1959.) Experimental investigation of sound propagation in a medium in which the square of the refractive index varies according to an exponential law.

A list of organizations which have available English translations of Russian journals in the electronics and allied fields appears at the end of the Abstracts and References section.

The Index to the Abstracts and References published in the PROC. IRE from February, 1959 through January, 1960 is published by the PROC. IRE, June, 1960, Part II. It is also published by *Electronic Technology* (incorporating *Wireless Engineer* and *Electronic and Radio Engineer*) and included in the April, 1960 issue of that Journal. Included with the Index is a selected list of journals scanned for abstracting with publishers' addresses.

534.2–13 **1085**
On the Diffusion of Sound Waves in a Turbulent Atmosphere—R. H. Lyon. (*J. Acoust. Soc. Amer.*, vol. 31, pp. 1176–1182; September, 1959.) The directional and frequency diffusion of a plane monochromatic sound wave in statistically homogeneous, isotropic, and stationary turbulence is analyzed theoretically.

534.2–14:534.88 **1086**
Model Experiments on Sound Propagation in Shallow Seas—A. B. Wood. (*J. Acoust. Soc. Amer.*, vol. 31, pp. 1213–1235; September, 1959.) Detailed report of an experimental study including a description of a scanning technique which gives a complete picture of a low-intensity sound field in a vertical plane in the water.

534.213–8 **1087**
Measurement of Velocity and Attenuation of Ultrasonic Surface Waves in Solid Materials—K. N. Vinogradov and G. K. Ul'yanov. (*Akust. Z.*, vol. 5, no. 3, pp. 290–293; 1959.) Report of measurements made on metals, alloys and glass by a standing-wave method using a proximity magneto-acoustic converter. Damping was measured by a pulse method. Oxidation of an alloy sample increased the surface-wave attenuation at 8 mc from 0.08 to 0.25 db/cm.

534.213.4 **1088**
Characteristic Parameters of Propagation in Lined Ducts—R. S. Piazza. (*Acustica*, vol. 9, no. 3, pp. 129–134; 1959.)

534.213.4 **1089**
Three-Dimensional Investigation of the Propagation of Waves in Hollow Circular Cylinders: Parts 1 and 2—D. C. Gazis. (*J. Acoust. Soc. Amer.*, vol. 31, no. 5, pp. 568–578; May, 1959.) The frequency equation for the propagation of free harmonic waves along a cylinder of infinite extent is derived and evaluated for some representative cylinders.

534.232–8:537.228.1 **1090**
On the Spatial Resolving Power of Barium Titanate and Quartz Plates for Ultrasonic-Field Imaging—K. Hartwig. (*Acustica*, vol. 9, no. 2, pp. 109–117; 1959. In German.) Acoustic measurements of the amplitude distribution of forced vibrations of different-sized plates in the range 3.9–9.5 mc and with excitation restricted to a narrow region of the plate, are considered in relation to electrical measurements of their natural vibrations. Optimum thickness and frequency limits for piezoelectric plates in ultrasonic image converters [see *e.g.* 2084 of 1959 (Freitag and Martin)] are discussed.

534.26 **1091**
Diffraction of a Convergent Cylindrical Wave by a Sphere—I. N. Kanevskiĭ. (*Akust. Z.*, vol. 5, no. 3, pp. 294–300; 1959.) An expression is derived for the resulting field potential and asymptotic expressions are obtained for the intensity of the scattered wave and the effective scattering cross section.

534.283:546.621 **1092**
Acoustic Attenuation in Aluminium due to Electron-Lattice Interaction—E. Lax. (*Phys. Rev.*, vol. 115, pp. 1591–1594; September 15, 1959.) Measured attenuation was proportional to the electrical conductivity and increased with the square of the frequency, but was 50 per cent greater then could be explained by existing theory.

534.283–8:546.815:538.6 **1093**
The Effect of the Direction of a Transverse Magnetic Field on the Electronic Component of Ultrasonic Absorption in a Lead Single Crystal—L. Mackinnon, A. Myers, and M. T. Taylor. [*Proc. Phys. Soc.* (*London*), vol. 75, pp. 773–775; December 1, 1959.]

534.286–14 **1094**
Compressional Relaxation in Liquids—R. E. Nettleton. (*J. Acoust. Soc. Amer.*, vol. 31, pp. 557–567; May, 1959.)

534.286.2 **1095**
The Oscillation of Air Particles in Porous Sound-Absorber Models—H. W. Helberg. (*Acustica*, vol. 9, no. 3, pp. 155–163; 1959. In German.) Entry impedance is calculated for a given Rayleigh-type model and the damping and phase velocity in front of the absorber are determined for grazing incidence. Measurements on three models placed on the walls of a rectangular tube are described.

534.286.2 **1096**
Absorption of Sound by a Strip of Absorptive Material in a Diffuse Sound Field—T. D. Northwood, M, T. Grisaru, and M. A. Medcof. (*J. Acoust. Soc. Amer.*, vol. 31, pp. 595–599; May, 1959.) The method of Levitas and Lax (2314 of 1951) is extended to determine random-incidence absorption.

534.62 **1097**
The New Anechoic Room of the Centre National d'Ètudes des Télécommunications—P. Chavasse and R. Lehmann. (*Ann. Télécommun.*, vol. 14, pp. 72–83; March/April,

1959.) The construction of the room is described in detail and its acoustic characteristics are given.

534.75 1098

Binaural Listening and Interaural Noise Cross-Correlation—I. Pollack and W. J. Trittipoe. (*J. Acoust. Soc. Amer.*, vol. 31, pp. 1250–1252; September, 1959.) The identification of different interaural correlations is examined over a wide range of reference correlations.

534.76:621.395.623.7 1099

Listener Reaction to Stereophonic Reproduction by Reflected Sound—S. E. Levy, G. W. Sioles, V. Brociner, and R. W. Carlisle. (*J. Acoust. Soc. Amer.*, vol. 31, pp. 1256–1259; September, 1959.) Data are presented on the evaluation of various loudspeaker arrangements making use of reflections from the walls of the room in which the stereophonic sound field is produced.

534.79 1100

Curves of Equal Loudness for Octave-Filtered Noise in a Diffuse Sound Field—L. Cremer, G. Plenge, and D. Schwarzl. (*Acustica*, vol. 9, no. 2, pp. 65–75; 1959. In German.) Measurement equipment and its mode of operation are described. A noise-level meter based on data for a diffuse sound field showing a fall of about 3 db per octave is considered.

534.79 1101

On the Lambda Loudness Function, Masking, and the Loudness of Multicomponent Tones—W. R. Garner. (*J. Accoust. Soc. Amer.*, vol. 31, pp. 602–607; May, 1959.) A computational procedure is presented for determining the loudness of multicomponent tones. See 1062 of 1959.

534.833:534.286.2 1102

Three-Dimensional Multiresonant Sound Absorber—M. Abramchik and I. Maletskiĭ. (*Akust. Z.*, vol. 5, no. 3, pp. 275–281; 1959.) Description of a small absorber with perforated flexible walls of transparent material which can be hung from the ceiling. An experimental investigation of the optimum height and spacing of absorbers for noise reduction is reported.

621.395.623.7.001.4 1103

Measurements on Loudspeakers in their Places of Use—T. S. Korn and J. Hougardy. (*Acustica*, vol. 9, no. 3, pp. 121–126; 1959. In French.) Response curves of different loudspeaker units measured a) in an echo-free chamber and b) in listening rooms are compared. The lack of correlation between the two sets of curves is underlined. "Room amplification" is defined and a standard-listening-room procedure is suggested for practical measurements.

621.395.625.3 1104

The Recording Process in Magnetic Sound Recording in Preisach's Representation—G. Schwantke. (*Frequenz*, vol. 12, pp. 383–394; December, 1958.) The analysis of magnetization processes on the basis of Barkhausen-jump statistics using the Preisach diagram is developed. The study of the recording mechanism by this method provides a satisfactory explanation of certain observed effects (see 375 of February), and may give a quantitative interpretation of the recording process.

681.844.08 1105

Analysis of a Piezoelectric Phonograph Transducer as a Function of the Clamping Position—D. H. Howling. (*J. Acoust. Soc. Amer.*, vol. 31, pp. 620–627; May, 1959.) Recording and play-back response characteristics of a laterally vibrating transducer are investigated using a transmission-line analog.

ANTENNAS AND TRANSMISSION LINES

621.372.8:537.226 1106

An Image-Line Coupler—D. J. Angelakos. (Trans. IRE on Microwave Theory and Techniques, vol. MTT-7, pp. 391–392; July, 1959.) A study of the coupling due to a hole made through the image plane. Results obtained with an experimental coupler at 24.4 kmc and a note on its application as a directional coupler are given.

621.372.823:621.372.852.22 1107

Propagation Constants of Circular Cylindrical Waveguides Containing Ferrites—H. K. F. Severin. (Trans. IRE on Microwave Theory and Techniques, vol. MTT-7, pp. 337–346; July, 1959. Abstract, Proc. IRE, vol. 47, p. 1796; October, 1959.)

621.372.826 1108

O-Guide and X-Guide: an Advanced Surface-Wave Transmission Concept—M. Sugi and T. Nakahara. (Trans. IRE on Microwave Theory and Techniques, vol. MTT-7, pp. 366–369; July, 1959. Abstract, Proc. IRE, vol. 47, p. 1796; October, 1959.)

621.372.829 1109

The Transmission of TE_{01} Wave in Helix Waveguides—T. Hosono and S. Kohno. (Trans. IRE on Microwave Theory and Techniques, vol. MTT-7, pp. 370–378; July, 1959. Abstract, Proc. IRE, vol. 47, p. 1796; October, 1959.)

621.372.831 1110

Design of Linear Double Tapers in Rectangular Waveguides—R. C. Johnson. (Trans. IRE on Microwave Theory and Techniques, vol. MTT-7, pp. 374–378; July, 1959. Abstract, Proc. IRE, vol. 47, p. 1796; October, 1959.)

621.372.831 1111

Spurious Mode Generation in Nonuniform Waveguide—L. Solymar. (Trans. IRE on Microwave Theory and Techniques, vol. MTT-7, pp. 379–383; July, 1959. Abstract, Proc. IRE, vol. 47, p. 1796; October, 1959.)

621.372.831.2 1112

Waveguide Bend—D. Wray and R. A. Hastie. (*Electronic Tech.*, vol. 37, pp. 76–83; February, 1960.) A design procedure is given for a sharp bend of continuously changing radius of curvature. Results obtained with an experimental bend compare favorably with those for a "slow" bend of considerably greater size.

621.372.832.6 1113

A High-Power Diplexing Filter—L. Young and J. Q. Owen. (Trans. IRE on Microwave Theory and Techniques, vol. MTT-7, pp. 384–387; July, 1959. Abstract, Proc. IRE, vol. 47, pp. 1796–1797; October, 1959.)

621.372.832.8 1114

New Microwave Circulators—H. N. Chait and T. R. Curry. (*Electronics*, vol. 32, pp. 81–83; December 18, 1959.) The operation of the Y-circulator is explained, and different methods of introducing the ferrite are discussed. Experimental results are given, and advantages and applications of the circuit are described.

621.372.832.8 1115

Circulators at 70 and 140 kMc/s—J. B. Thaxter and G. S. Heller. (Proc. IRE, vol. 48, pp. 110–111; January, 1960.) The design of H-plane Y-junctions and their insertion loss and isolation characteristics are given.

621.372.832.8 1116

A Strip-Line L-Band Compact Circulator—L. Davis, Jr., U. Milano, and J. Saunders. (Proc. IRE, vol. 48, pp. 115–116; January, 1960.) Isolation, insertion loss and VSWR characteristics are given for a symmetrical Y-type junction.

621.372.837.3 1117

A Ferrite Cutoff Switch—R. F. Soohoo. (Trans. IRE on Microwave Theory and Techniques, vol. MTT-7, pp. 332–336; July, 1959. Abstract, Proc. IRE, vol. 47, p. 1796; October, 1959.) See also 1974 of 1958.

621.396.674.3 1118

The Driving-Point Impedance of Cylindrical Antennas Conically Tapering at the Base—R. Kümmich. (*Frequenz*, vol. 12, pp. 369–379; December, 1958.) Results are given of impedance measurements on microwave antennas which are conically tapered at the junction with the coaxial feeder. Locus curves of input impedance as a function of diameter/length ratio d/l are plotted for tapers of 45 degrees, 60 degrees and 90 degrees. Curves of resistance as a function of d/l for current and voltage resonances are derived, and comparisons are made with the results obtained by other authors.

621.396.674.3 1119

The Performance of a Balanced Aerial when Connected Directly to a Coaxial Cable—G. D. Monteath and P. Knight. (*Proc. IEE*, Part B, vol. 107, pp. 21–25; January, 1960.) Various configurations are discussed. Measured vertical and horizontal polar diagrams are given for dipoles and Yagi arrays having their elements vertical, and with the driven element connected directly to the coaxial down-lead. The vertical radiation patterns are appreciably distorted (less for arrays than for a dipole), and the sensitivity to interference from sources near to and below the antenna is increased.

621.396.676:629.19 1120

Aerials in Space—M. G. Chatelain. (*Onde élect.*, vol. 39, pp. 785–788; October, 1959.) Problems associated with communication in space are examined and the spherical equiangular spiral is proposed as a suitable antenna, having the required characteristics of large bandwidth and variable polarization.

621.396.677.3 1121

Pattern Synthesis—Simplified Methods of Array Design to Obtain a Desired Directive Pattern—G. H. Brown. (*RCA Rev*, vol. 20, pp. 398–412; September, 1959.) Mathematical methods of determining the magnitude and phase of the current distribution over an extended linear antenna aperture are described. The radiation pattern and current distribution form a set of Fourier transforms.

621.396.677.83 1122

The Backfire Antenna, a New Type of Directional Line Source—H. W. Ehrenspeck. (Proc. IRE, vol. 48, pp. 109–110; January, 1960.) A Yagi antenna is directed at a plane reflector so that the surface wave traverses the elements a second time. Experimental results show that increases in gain greater than 3 db can be obtained.

AUTOMATIC COMPUTERS

681.142 1123

Computers and Computer Equipment Design—(*Electronic Equip. Engrg.*, vol. 7, pp. 63–98; October, 1959.) A group of nine papers on practical aspects of digital-computer design and recently developed techniques.

681.142 1124

Electronic Computers and the Electronic Computer Study Centre at Pisa—M. Conversi (*Nuovo Cim.*, vol. 11, Supplement no. 3, pp. 376–396; 1959.) Outline of the program and future development of the Center with detail of available equipment. See also 3966 of 1959 (Caracciolo and Guerri).

681.142 1125

Solid-State Digital Code-to-Code Converter—R. Wasserman and W. Nutting. (*Electronics*, vol. 32, pp. 60–63; December 11, 1959.) 13 bits of Gray code can be changed to normal binary code by means of the converter described. The basic building block is a circuit comprising a magnetic core, a junction transistor, and a delay network. Thyratrons are used for the read-out display.

681.142 1126

A High-Speed Ferrite Storage System—C. J. Quartly. (*Electronic Engrg.*, vol. 31, pp. 756–758; December, 1959.) A read/write cycle time of 0.5 μsec can be achieved in the small store described.

681.142 1127

The Magnetic Drum Store of the "Mercury" Computer—K. I. Turner and J. E. Thompson. (*Electronic Engrg.*, vol. 32, pp. 16–21; January, 1960.) Explanatory circuit diagrams, mechanical drawings, and performance data of the Type-1909 drum are given.

681.142 1128

Approximation Errors in Diode Function Generators—N. Ream. (*J. Electronics Control*, vol. 7, pp. 83–96; July, 1959.) Errors resulting from fitting a piecewise-linear function to a smooth curve are discussed in relation to analog-computer applications. A simple integral based on best-fit criteria will give the relation between number of segments and error and also the break points between segments. Numerical results are given for typical functions.

681.142:621.374.3 1129

Theoretical Study and Method of Operation of a Logarithmic Integrator—R. G. Nicolo. (*Onde élect.*, vol. 39, pp. 816–822; October, 1959.) Description of a computer circuit based on a diode-pump action.

681.142:621.382.3 1130

The Construction of a Digital Computing System from a Basic Transistor Circuit—P. L. Cloot and G. E. Jackson. (*Electronic Engrg.*, vol. 32, pp. 37–43; January, 1960.) The computer uses 335 identical basic circuits to convert decimal numbers to and from the binary scale. Diagrams of the basic circuit and the system are given. Printed circuits are used.

681.142:621.383.4 1131

Light-Pen links Computer to Operator—B. M. Gurley and C. E. Woodward. (*Electronics*, vol. 32, pp. 85–87; November 20, 1959.) Using a photodiode to read dots produced on a cr tube enables an operator to control an associated computer. By pointing the light-pen at certain dots, information can be written in to the computer.

681.142:621.391.812.8 1132

Computers aid Propagation Studies—(*See* 1375.)

681.142:621.397.3 1133

Automatic Character Recognition—D. A. Young. (*Electronic Engrg.*, vol. 32, pp. 2–10; January, 1960.) Limitations and future developments of existing machines are discussed. Further analysis of the semantic features of character patterns and of their recognition limits leads to a "semantic pattern definition" which is sufficiently general to permit recognition of nearly illegible characters.

681.142:697.9 1134

How Analogue Networks Solve Air-Conditioning Problems—W. L. Wright and C. A. Booker. (*Electronics*, vol. 32, pp. 34–37; December 25, 1959.) The thermal properties of a unit area of the structural elements are represented by an equivalent electrical circuit. A complete block diagram shows how these are used to simulate the thermal behavior of a room and its air conditioning system. Some detailed circuitry is given.

CIRCUITS AND CIRCUIT ELEMENTS

621.3.049.7 1135

Three Approaches to Microminiaturization—R. Langford. (*Electronics*, vol. 32, pp. 49–52; December 11, 1959.) Construction methods for extremely small electronic circuits are detailed.

621.3.049.7 1136

British Approaches to Microminiaturization—G. W. A. Dummer. (*Electronics*, vol. 33, pp. 71–75; January 1, 1960.) See 409 of February.

621.318.4.042.1:621.397.62 1137

The Properties of Ferrite U-Cores for Horizontal-Deflection Output Transformers—R. Fälker and E. E. Hücking. (*Elektron. Rundschau*, vol. 13, pp. 3–9; January, 1959.) The results of measurements made with a special core tester (3057 of 1959) are given and discussed.

621.318.57 1138

Steering Circuits control Reversible Counters—R. D. Carlson. (*Electronics*, vol. 33, pp. 86–88; January 1, 1960.) A four-stage bistable multivibrator system is used to provide decade counting. Complementary outputs from each stage are switched to succeeding stages to give either addition or subtraction.

621.318.57:621.382.3 1139

Approximate Calculation of Bistable Switching Circuits using Junction Transistors. Case of Switching Circuits with Common Emitter Resistance—C. Mira. (*Compt. rend.* vol. 249, pp. 384–386; July 20, 1959.) Application of the method described earlier for the case of double-bias operation (53 of January).

621.319:537.226/.228.1 1140

Dielectric Devices—G. T. Wright. (*Nature*, vol. 185, pp. 360–361; February 6, 1960.) Report of a conference held in the Electrical Engineering Department of the University of Birmingham, September 14–17, 1959.

621.372:517.942 1141

On Stochastic Linear Systems—J. C. Samuels and A. C. Eringen. (*J. Math. Phys.*, vol. 38, pp. 83–103; July, 1959.) Systems governed by *n*th-order linear differential equations having random coefficients are studied and the methods developed are applied to a RLC circuit having random capacitance variations.

621.372.413 1142

Design of Open-Ended Microwave Resonant Cavities—D. C. Thorn and A. W. Straiton. (TRANS. IRE ON MICROWAVE THEORY AND TECHNIQUES, vol. MTT-7, pp. 389–390; July, 1959.) Two types of cavity for refractive-index measurements are described, one rectangular in cross section, the other cylindrical. The cavities are terminated in short sections partitioned so that each subdivision is a waveguide operating below the cut-off frequency of the cavity.

621.372.413:678.5 1143

Plastic Microwave Cavities for EPR—P. F. Chester, P. E. Wagner, J. G. Castle, Jr., and G. Conn. (*Rev. Sci. Instr.*, vol. 30, pp. 1127–1128; December, 1959.) An X-band TE_{102} plastic cavity for studies of relaxation in electron paramagnetic resonance is described. It has a Q of 4000 at room temperature and 6000 at 4.2°K.

621.372.44 1144

Generalization to Nonlinear Networks of a Theorem due to Heaviside—S. Duinker. (*Philips Res. Rep.*, vol. 14, pp. 421–426; October, 1959.) A theorem, enunciated by Heaviside and proved by Lorentz for linear electromagnetic systems subjected to a suddenly impressed constant electric force, is extended to electrical networks comprising nonlinear reactances and linear resistance.

621.372.5 1145

Classes of 4-Pole Networks having Nonlinear Transfer Characteristics but Linear Iterative Impedances—E. C. Cherry. (PROC. IRE, Part B, vol. 107, pp. 26–30; January, 1960.) A graphical representation is introduced which simplifies the analysis of networks containing nonlinear elements. The properties of "dual" nonlinear resistances, in which the I/V relation for one resistance is the same as the V/I relation for the other are considered. Such "duals," if realizable, would permit the design of nonlinear four-poles having linear iterative impedances, which could be cascaded.

621.372.5:621.391.822 1146

Theory of Noisy Two-Port Networks—E. F. Bolinder. (*J. Franklin Inst.*, vol. 267, pp. 1–23; January, 1959.) The geometric-analytic theory presented is based on the isometric-sphere method (see 17 of 1958) and on a three-dimensional conformal transformation. 50 references.

621.372.51 1147

Impedance Transformations through Lossless Two-Ports Represented by Fractional Linear Transformations of the Unit Circle—K. Jost. (*Philips Res. Rep.*, vol. 14, pp. 301–326; August, 1959.) The automorphism of a unit circle corresponding to an impedance transformation is characterized by three parameters and can be represented by three successive elementary transformations. This leads to a simple graphical method using Carter or Smith charts for the determination of the transformed impedance and for the treatment of cascades of lossless two-ports.

621.372.54 1148

Constant-Resistance All-Pass Networks with Maximally Flat Time Delay—L. Weinberg. (*J. Franklin Inst.*, vol. 267, pp. 35–53; January, 1959.) Practical design tables are given and their use is illustrated by examples.

621.372.54 1149

The Loss Attenuation in the Pass Band of Wave Filters with Differing Coil Q-Factors—J. Böhse. (*Frequenz*, vol. 12, pp. 380–383; December, 1958.) The loss contributions of the individual coils are summed using weighting functions. Application of the method to a crystal-filter half-section is explained.

621.372.544:621.374.5 1150

An Analysis of a Type of Comb Filter—A. G. J. MacFarlane. (*Proc. IEE*, Part B, vol. 107, pp. 39–52; January, 1960.) A theoretical analysis and discussion of practical devices for use in radar as moving-target indicators and signal integrators. 28 references.

621.372.6:621.391 1151

Calculation of the Static Characteristic of a Nonlinear Multipole without Inertia when the Dynamic Characteristic is Known—G. Papadopoulov. (*Ann. Télécommun.*, vol. 14, pp. 43–48; January/February, 1959.)

621.372.63:621.372.54 1152

High-Frequency Transistor Filter Synthesis—L. M. Vallese. (*Electronic Engrg.*, vol. 31, pp. 748–752; December, 1959.) Two canonical ladder structures of hybrid-Π and hybrid-T type are considered. The intrinsic feedback factor is ignored. Examples of cascaded structures are given.

621.373.4 1153

The Effect of Cathode Impedance on the Frequency Stability of Linear Oscillators—C. T. Kohn. (PROC. IRE, vol. 48, pp. 80–88; January, 1960.) Long-term frequency instability, due to the growth of an interface layer between oxide coating and cathode, may be reduced by suitably adjusting the ratio of anode-to-grid RF voltages.

621.373.4:621.396.62 1154

Voltage Sensitivity of Local Oscillators—W. Y. Pan. (*RCA Rev.*, vol. 20, pp. 473–484; September, 1959.) The dependence of the oscillation frequency of tube oscillators on certain operating conditions is discussed and defined mathematically in terms of independent variables.

621.373.44 1155

How to Generate Accurate Sawtooth and Pulse Waves—C. A. Von Urff and R. W. Ahrons. (*Electronics*, vol. 32, pp. 64–66; December 11, 1959.) Two circuits giving stable sawtooth and rectangular pulse outputs are described, in which a high-speed switching transistor is controlled by a Zener diode. Pulse width and amplitude and waveform timing are independent of active elements in the circuit.

621.374.4 1156

A Method of Combining Two Frequencies—L. R. Kahn. (PROC. IRE, vol. 48, pp. 118–119; January, 1960.) A new method of frequency synthesis is described in which two equal-amplitude tones are combined by limiting, phase inverting and selecting the correct polarity at a control gate.

621.375.012 1157

The Definition of Noise Factor when Applied to Systems containing Negative-Resistance Elements—B. L. Humphreys. (*J. Electronics Control*, vol. 7, pp. 77–81; July, 1959.) The concept of available power and the definition of noise factor are extended to include negative resistance by using the idea of exchangeable power. See 2387 of 1957 (Haus and Adler).

621.375.227 1158

Wide-Band Analysis of Valve Phase-Splitting Circuits—L. J. Giacoletto. (*Electronic Engrg.*, vol. 31, pp. 733–735; December, 1959.) Accurate and approximate design data are developed and compared with results of measurements. Near-ideal operating conditions can be obtained up to a few megacycles with suitable load impedances.

621.375.4 1159

Analysis of the Transistor Cascode Configuration—J. R. James. (*Electronic Engrg.*, vol. 32, pp. 44–48; January, 1960.) Neutralization is not necessary; more gain per unit volume and weight is achieved than in other transistor configurations, while cost per unit gain is about equal to that of more conventional circuits.

621.375.4:621.395.665.1 1160

Transistor Constant-Volume Amplifier—G. J. Pope. (*Wireless World*, vol. 66, pp. 88–91; February, 1960.) Design and circuit details of a microphone amplifier providing substantially similar output signal levels for various speech input levels.

621.375.4.029.33:621.397.6 1161

Transistors in Video Equipment—P. B. Helsdon. (*J. Brit. IRE*, vol. 19, pp. 753–767; December, 1959. Discussion, p. 768.) The importance of the product current-gain × bandwidth is discussed. A new design method is described which gives greater gain-bandwidth factors. The conditions for maximum signal-to-noise ratio are determined and confirmed experimentally. Signal-to-noise ratios and gain-bandwidth factors are comparable to those of tubes.

621.375.4.121.2 1162

Transistorized Distributed Amplifier—C. W. McMullen. (*Rev. Sci. Instr.*, vol. 30, pp. 1109–1113; December, 1959.) The characteristic impedance of both the base and collector transmission lines is 43.4 Ω. A four-section amplifier stage has a gain of about 5 db from 10 cps to 200 mc.

621.375.9:538.569.4 1163

Solid-State Maser Amplifier—S. A. Ahern. (*Electronic Tech.*, vol. 37, pp. 59–63; February, 1960.) The principles of maser operation are introduced and the essential details of a practical cavity maser system are described.

621.375.9:538.569.4 1164

Maser Operation with Signal Frequency Higher than Pump Frequency—F. R. Arams. (PROC. IRE, vol. 48, p. 108; January, 1960.) An X-band solid-state maser is described using the four Zeeman levels in ruby.

621.375.9:538.569.4 1165

Investigation of the Oscillation Voltage of a Strong-Field Maser-Type Self-Oscillator—H. Benoit and C. Fric. (*Compt. rend.*, vol. 249, pp. 537–539; July 27, 1959.) Investigation of a maser of the type described earlier (798 of March) in which the macroscopic polarization of the protons is made antiparallel to the directive field. Experimental and theoretical E/Q curves are shown for different rates of flow.

621.375.9:621.372.44 1166

Experimental Verification of Parametric-Amplifier Excess Noise using Transformer Coupling—S. Cohen. (PROC. IRE, vol. 48, pp. 108–109; January, 1960.) A method is described for measuring noise temperature at frequencies where circulators are not available.

621.375.9:621.372.44:621.372.2 1167

An Analysis of Parametric Amplification in Periodically Loaded Transmission Lines—G. H. Heilmeier. (*RCA Rev.*, vol. 20, pp. 442–454; September, 1959.) The propagating structure is considered as a lossless transmission line periodically loaded with nonlinear capacitance in the form of back-biased semiconductor diodes. Information is given about the relation of diode parameters, spacing and circuit parameters to the gain and bandwidth of the structure.

621.375.9:621.372.44:621.385.63 1168

Fast-Wave Couplers for Longitudinal-Beam Parametric Amplifiers—Ashkin, Louisell, and Quate. (*See* 1449.)

621.375.9:621.376.029.65 1169

Three-Level Maser Detector for Ultra Microwaves—K. Shimoda (*J. Phys. Soc. Japan*, vol. 14, p. 966; July, 1959.) Note on the principles of a device similar to the spectrometer described earlier (*see* 1355 below). The absorption at ultramicrowave frequencies changes the population of levels and results in an increase or decrease of absorption at a lower microwave frequency.

621.375.9.121.2:621.372.44 1170

Mode Theory of Lossless Periodically Distributed Parametric Amplifiers—K. Kurokawa and J. Hamasaki. (TRANS. IRE ON MICROWAVE THEORY AND TECHNIQUES, vol. MTT-7, pp. 360–365; July, 1969. Abstract, PROC. IRE, vol. 47, p. 1796; October, 1959.)

621.376.32:621.382.3 1171

Reactance Transistor—Y. Fujimura and N. Mii. (PROC. IRE, vol. 48, p. 118; January, 1960.) Frequency deviation curves calculated from the theoretical output admittance are compared with measurements for a given FM oscillator circuit.

GENERAL PHYSICS

53.081.6 1172

On Explanations of Electric and Magnetic Constants and Units—A. T. Gresky. (*J. Franklin Inst.*, vol. 267, pp. 201–210; March, 1959.) Using dimensional methods, the relation of free-space dielectric constant, and magnetic permeability constant to four fundamental quantities is considered. Other constants are also analyzed to obtain methods of understanding the submicroscopic nature of electric and magnetic phenomena. See also 3752 of 1958.

537.311.1 1173

Variational Approach to Deviations from Ohm's Law—I. Adawi. (*Phys. Rev.*, vol. 115, pp. 1152–1156; September 1, 1959.) Kohler's variational method has been used to obtain deviations from Ohm's law for a nondegenerate electron gas. Two important applications of the method are discussed.

537.311.33 1174

Many-Particle Approach to the One-Electron Problem of Insulators and Semiconductors—A. Klein. (*Phys. Rev.*, vol. 115, pp. 1136–1146; September 1, 1959.) Motion of an electron near the bottom of the conduction band in the presence of external electric and magnetic fields, whose variation over one lattice spacing is small, is governed by a simple Schrödinger equation.

537.312.8 1175

Energy Levels of Conduction Electrons in a Magnetic Field—Y. Yafet. (*Phys. Rev.*, vol. 115, pp. 1172–1176; September, 1959.) The energy levels can be obtained simply if the spherical approximation is made for the band structure. The free energy due to small departures from this assumption may be estimated using perturbation theory. Inclusion of spin-orbit coupling gives the g factor as a function of position in the band.

537.525 1176

The Current Sheet in a Gas Discharge—N. J. Phillips. (*Proc. Phys. Soc.* (*London*), vol. 74, pp. 700–704; December 1, 1959.) Deals with the trapping of cold gas in the sheet.

537.525:538.63 1177

Studies of Cold-Cathode Discharges in Magnetic Fields—J. Backus. (*J. Appl. Phys.*, vol. 30, pp. 1866–1869; December, 1959.) The current is 75 per cent ionic. Mass-spectrometer measurements were made to determine the ion energies. The mechanism of the discharge is discussed.

537.533.8 1178

Theory of Secondary Electron Emission of Metals: the Excitation Process—H. W. Streitwolf. [*Ann. Phys.*, (*Lpz.*), vol. 3, pp. 183–196; March 24, 1959.] See also 1179 below and 3757 of 1959 (Stolz & Streitwolf).

537.533.8 1179

Theory of Secondary Electron Emission of Metals: the Transport Process—H. Stolz. [*Ann. Phys.*, (*Lpz.*), vol. 3, pp. 197–210; March 24, 1959.]

537.56 1180

Conductivity of a Warm Plasma—L. Mower (*Phys. Rev.*, vol. 116, pp. 16–18; October 1, 1959.) "A theory for obtaining the conductivity of a uniform plasma as a function of frequency and temperature is presented and compared with a number of recent treatments."

537.56 1181

Experiments with Plasma Rings—L. Lindberg, E. Witalis, and C. T. Jacobsen. (*Nature*, vol. 185, pp. 452–453; February 13, 1960.) A brief description is given of a plasma gun discharging into a glass drift tube. Measurements have been made of the circuit current and the magnetic flux carried by the plasma.

537.56:538.56 1182

Oscillations in Plasma: Part 2.—S. Kojima, K. Kato, S. Hagiwara, and R. Matsuzaki. (*J. Phys. Soc. Japan*, vol. 14, pp. 821–827; June, 1959.) Discrete oscillations reported in Part 1 (1699 of 1958) are studied in detail. Oscillations at the higher frequency are generated by the convergent beam in the central part of the tube, while those at the lower frequency seem to be generated near the wall of the tube by the divergent beam. Another oscillation having an intermediate frequency is often observed.

537.56:538.561 1183

Occurrence of Vavilov-Čerenkov Radiation in a High-Temperature Plasma—J. Neufeld. (*Phys. Rev.*, vol. 116, pp. 1–3; October 1, 1959.) Analytical results indicate that radiation is not emitted by a particle moving through a high-temperature plasma at a velocity lower than the mean thermal velocity of plasma electrons.

537.56:538.566 1184

Longitudinal and Transverse Waves in a Lorentz Plasma—K. Rawer and K. Suchy. [*Ann. Phys.* (*Lpz.*), vol. 3, pp. 155–170; March 24, 1959.] The triple refraction in inhomogeneous plasma is discussed. See also 3641 of 1959.

537.56:538.6 1185

Radial Hydromagnetic Oscillations—G. B. F. Niblett and T. S. Green [*Proc. Phys. Soc.* (*London*), vol. 74, pp. 737–743; December 1, 1959.] The equation of motion of radial hydromagnetic oscillations of a plasma confined by an axial magnetic field is integrated and shown to give good agreement with experiment.

537.56:538.63 1186

Discharge Phenomena in Lorentz-Type Plasmas: Investigation of Electron Distribution in the Presence of a Magnetic Field—P. Maroni. (*Compt. rend.*, vol. 249, pp. 881–883; August 24, 1959.) A partial differential equation derived by Kahan and Jancel (see 3453 of 1957 and back references) is integrated for the case where the collision frequency is constant. (For further discussion see *ibid.*, vol. 249, pp. 914–916; August 31, 1959.)

538.566:535.42]+534.26 1187

The Half-Plane Diffraction Problem for Harmonic Time Dependence—A. P. Burger. [*Proc. Roy. Soc.* (*London*), *A*., vol. 252, pp. 411–417; September 29, 1959.] "Green's functions are obtained for the boundary-value problems of mixed type describing the general two-dimensional diffraction problems at a screen in the form of a half-plane (Sommerfeld's problem), applicable to acoustically rigid or soft screens, and to the full electromagnetic field at a perfectly conducting screen."

538.566:535.42 1188

The Diffraction of Scalar Waves on Paraboloids of Revolution—K. Klante. [*Ann. Phys.* (*Lpz.*), vol. 3, pp. 171–182; March 24, 1959.]

538.566:535.42 1189

Diffraction by an Imperfectly Conducting Right-Angled Wedge—W. E. Williams. (*Proc. Camb. Phil. Soc.*, vol. 55, Part 2, pp. 195–209; April, 1959.) An exact solution is given for the diffraction of the field of an electric line current by an imperfectly conducting wedge of exterior angle $3\pi:2$.

538.566:535.42 1190

Diffraction of an E-Polarized Plane Wave by an Imperfectly Conducting Wedge—W. E. Williams. [*Proc. Roy. Soc.* (*London*) *A*, vol. 252, pp. 376–393; September 29, 1959.] A new and exact solution is obtained for arbitrary wedge angle.

538.566:538.6 1191

Propagation of Electromagnetic Waves in a Multistream Medium at Gyromagnetic Resonance—J. Neufeld. (*Phys. Rev.*, vol. 116, pp. 19–20; October 1, 1959.) Formulas are derived for the dispersion and the gyromagnetic resonance effects.

538.569.4 1192

Measurement Broadening in Magnetic Resonance—O. E. Myers and E. J. Putzer. (*J. Appl. Phys.*, vol. 30, pp. 1987–1991; December, 1959.) Phase-detection techniques cause broadening: a method for correcting observed widths is described.

538.652 1193

Form Effect in Magnetostriction—R. Gersdorf. (*J. Appl. Phys.*, vol. 30, pp. 2018–2019; December, 1959.) Comment on 2930 of 1959 (Stauss).

539.2:537.311.33:537.52 1194

A Simplified Theory of Two-Carrier, Space-Change-Limited Current Flow in Solids—M. A. Lampert. (*RCA Rev.*, vol. 20, pp. 682–701; December, 1959.)

539.2:538.222 1195

Zeeman Splitting of Paramagnetic Atoms in Crystalline Fields—H. Statz and G. F. Koster. (*Phys. Rev.*, vol. 115, pp. 1568–1577; September 15, 1959.) Energy levels of paramagnetic ions in crystalline surroundings are treated as a function of magnetic field.

539.2:538.6 1196

Theory of Block Electrons in a Magnetic Field: the Effective Hamiltonian—W. Kohn. (*Phys. Rev.*, vol. 115, pp. 1460–1478; September 15, 1959.) For a nondegenerate band the eigenstates of the Hamiltonian of a Block electron in a static magnetic field can be calculated from an equivalent Hamiltonian whose properties and formulation are discussed.

GEOPHYSICAL AND EXTRATERRESTRIAL PHENOMENA

523.152:629.19:061.3 1197

Symposium on the Exploration of Space—(*J. Geophys. Res.*, vol. 64, pp. 1647–1800; November, 1959.) The text is given with subsequent discussion of twelve papers read at a symposium in Washington, D. C., April 29–30, 1959.

523.164 1198

National Radio Astronomy Observatory—R. M. Emberson. (*Science*, vol. 130, pp. 1307–1318; November 13, 1959.) The history and development of the radio observatory at Green Bank, W. Va., are reviewed.

523.164 1199

The Mullard Radio Astronomy Observatory—M. Pyle. (*J. IEE*, vol. 6, pp. 14–19; January, 1960.) Two aperture-synthesis radio telescopes installed near Cambridge, Eng., are described and an outline is given of the present research program.

523.164:621.396.677.833 1200

The 600-Foot Radio Telescope—E. F. McClain, Jr. (*Sci. Amer.*, vol. 202, pp. 45–51; January, 1960.) Description of the steerable telescope under construction in West Virginia.

523.164.32:523.78 1201

Observations on the Solar Eclipse of October 2—J. Aarons, J. P. Castelli, R. M. Straka, and W. C. Kidd. (*Nature*, vol. 185, pp. 230–231; January 23, 1960.) A report of measurements made simultaneously on 224, 1300 and 3000 mc at Hamilton, Mass., in 1959. At this location the sun rose partially eclipsed and was totally eclipsed at an elevation of about 1 degree.

523.165 1202

Nature of Corpuscular Radiation of the Upper Atmosphere—I. S. Shklovskiĭ, V. I. Krasovskiĭ, and Yu. I. Gal'perin. (*Izv. Ak. Nauk S.S.S.R.*, no. 12, pp. 1799–1806; 1959.) The concentration of particles in the solar corpuscular stream is sufficient to renew the corpuscules of the outer radiation belt over a period of only a few hours. An estimation is made of the energy spectrum of protons and the velocity of generation of hard corpuscles in the inner belt.

523.165 1203

Heavy Primary Cosmic Rays at Geomagnetic Latitude of 41°N—O. B. Young and H. Y. Chen. (*Phys. Rev.*, vol. 115, pp. 1719–1721; September 15, 1959.) Results from nine balloon flights at heights 70,000–100,000 feet. Charge spectra, flux, mean free paths and angular distributions are given.

523.165 1204

Primary Cosmic-Ray Proton and Alpha-Particle Intensities and their Variation with Time—P. Meyer. (*Phys. Rev.*, vol. 115, pp. 1734–1741; September 15, 1959.) Results of a series of high altitude balloon flights in 1957 and 1958 made primarily to investigate the short-term variations of primary protons and alpha particles.

523.165:523.152.3 1205

Cosmic-Ray Measurements in the Vicinity of Planets and some Applications: Part 1—Primary Cosmic Radiation—S. F. Singer and R. C. Wentworth. (*J. Geophys. Res.*, vol. 64, pp. 1807–1813; November, 1959.) The variation of the primary cosmic-ray intensity is calculated as a function of distance from a dipole in its equatorial plane. Scientific applications indicated include the determination of magnetic fields of the moon and planets.

523.165:523.75 1206

Low-Energy Cosmic-Ray Events associated with Solar Flares—G. C. Reid and H. Leinbach. (*J. Geophys. Res.*, vol. 64, pp. 1801–1805; November, 1959.) Details are given of 24 events during the period May, 1957–July, 1959 which have been detected by the measurement of ionospheric absorption in arctic regions.

523.165:537.746.5 1207

The Apparent Sidereal Daily Variation of Cosmic-Ray Intensity during the Recent Sunspot Minimum—S. P. Baliga and T. Thambyahpillai. (*Phil. Mag.*, vol. 4, pp. 973–984; August, 1959.)

523.165:550.385.4 1208

Magnetic Cut-Off Rigidities of Charged Particles in the Earth's Field at times of Magnetic Storms—P. Rothwell. (*J. Geophys. Res.*, vol. 64, pp. 2026–2028; November, 1959.) Cut-off rigidities are calculated for charged particles at various locations and for different distances of the storm cloud from the earth.

550.385 1209

The Transmission of Geomagnetic Disturbances through the Atmosphere and Inter-

planetary Space—J. H. Piddington. (*Geophys. J. R. Astr. Soc.*, vol. 2, pp. 173–189; September, 1959.) The theory of the propagation of slowly varying EM disturbances through partially ionized gas is developed and applied to the earth's atmosphere and interplanetary space. The medium is considered as two separate co-existing gases, an electron-ion plasma and neutral atoms which move to some extent independently. Quantitative results are given for a model atmosphere out to several earth radii.

550.385.37 1210
Studies of Magnetic Field Micropulsations with Periods of 5 to 30 Seconds—W. H. Campbell. (*J. Geophys. Res.*, vol. 64, pp. 1819–1826; November, 1959.) The studies were carried out in 1958 in southern California.

550.385.4:551.510.535 1211
Geomagnetic Storms and Ionospheric Disturbances—T. Obayashi. (*J. Radio Res. Labs, Japan*, vol. 6, pp. 375–514; June, 1959.) A collection of papers covering the morphology of geomagnetic and ionospheric storms, an application of the atmospheric dynamo theory to geomagnetic variations during disturbances and a study of hydromagnetic oscillations of the ionized upper atmosphere.

550.385.4:551.547 1212
The Relationship between Geomagnetic Variations and the Circulation at 100 mb—J. London, I. Ruff, and L. J. Tick. (*J. Geophys. Res.*, vol. 64, pp. 1827–1833; November, 1959.) A statistical study for a five-year period leads to the conclusion that there is no obvious relation between the two sets of data.

550.389.2 1213
Radio and the I.G.Y—R. L. Smith-Rose. (*Wireless World*, vol. 66, pp. 52–58; February, 1960.) Summaries of the data collected, the analyses used, and the knowledge obtained about the ionosphere and outer space during the I.G.Y.

551.501.81:061.3 1214
Proceedings of Fourth Meeting of the Joint Commission on Radio Meteorology of I.C.S.U—(*J. Atmos. Terr. Phys.*, vol. 15, pp. 181–293; October, 1959.) The text is given of papers presented at the Meeting held in New York, N. Y., August 14–16, 1957.

551.507.362.2+629.19 1215
Artificial Earth Satellites and Space Travel: Part 1—The Satellite Orbits and their Changes with Time—C. W. M. Tilenius. (*VDIZ.*, vol. 102, pp. 1–9; January 1, 1960.) A table is included giving full details of earth satellites and moon probes successfully launched up to September 18, 1959.

551.507.362.2 1216
Lunar and Solar Perturbations on Satellite Orbits—E. Upton, A. Bailie, and P. Musen. (*Science*, vol. 130, pp. 1710–1711; December 18, 1959.) The lunar and solar effects on perigee height for satellite orbits of large eccentricity are investigated.

551.510.535 1217
Determination of the True Distribution of Electron Density in the Ionosphere: Part 2—W. Becker. (*Arch. elekt. Übertragung*, vol. 13, pp. 26–32; January, 1959.) The accuracy of the methods summarized in Part 1 (3603 of 1955) is discussed. Results obtained without consideration of the geomagnetic field are found to be completely uncertain.

551.510.535 1218
On the Seasonal and Nonseasonal Annual Variations and the Semi-annual Variation in the Noon and Midnight Electron Densities of the F_2 Layer in Middle Latitudes: Part 2—T. Yonezawa. (*J. Radio Res. Labs. Japan*, vol. 6, pp. 651–668; October, 1959.) Previous work [4055 of 1959 (Yonezawa and Arima)] is continued using two groups of relatively high- and low-latitude stations. The seasonal variation for the high-latitude stations is markedly different from that of the low-latitude group while the nonseasonal variations do not show great differences between the groups. The semi-annual variations in the two graphs are also not markedly different.

551.510.535 1219
A Statistical Study of World-Wide Occurrence Probability of Spread-F: Parts 1 and 2—T. Shimazaki. (*J. Radio Res. Labs. Japan*, vol. 6, pp. 669–704; October, 1959.) Diurnal, seasonal and latitudinal variations in the occurrence of spread-F during the I.G.Y. are analyzed. Marked differences between high and low latitudes suggest an essentially different origin for the phenomenon in the two regions. The correlation of spread-F with geomagnetic activity is discussed and abnormal occurrences during magnetic storms are examined in detail.

551.510.535:061.3 1220
Proceedings of Fifth Meeting of the Mixed Commission on the Ionosphere of I.C.S.U.—(*J. Atmos. Terr. Phys.*, vol. 15, pp. 7–176; September, 1959.) The text is given of papers presented at the meeting held in New York, N. Y., August 14–16, 1957.

551.510.535:621.391.812.33:551.507.362.2 1221
The Ionospheric Faraday Effect and its Applications—F. B. Daniels and S. J. Bauer. (*J. Franklin Inst.*, vol. 267, pp. 187–200; March, 1959.) Measurements of ionospheric characteristics by means of lunar radio reflections and satellite radio transmissions using the Faraday effect are discussed.

551.510.535:621.391.812.63 1222
Influence of Absorption on the Reflection Coefficient of the Ionosphere—P. Poincelot. (*Ann. Télécommun.*, vol. 14, pp. 54–58; March /April, 1959.) The reflection coefficient of a stratified layer is considered, assuming that electron concentration varies linearly with height; absorption is represented by a viscous resistance proportional to the velocity of free electrons.

551.510.535(98):621.391.812.631:523.164.32 1223
Pre-SC Polar-Cap Ionospheric Blackout and Type IV Solar Radio Outburst—Y. Hakura and T. Goh. (*J. Radio Res. Labs, Japan*, vol. 6, pp. 635–650; October, 1959.) Short-wave radio blackouts in polar-cap regions are often found to occur well before the sudden-commencement magnetic storms and this phenomenon is closely correlated with the occurrence of type IV solar RF bursts. A possible explanation of these effects is given which is consistent with other related phenomena such as cosmic-ray storms.

551.510.535 "1959" 1224
Ionosphere Review 1959—T. W. Bennington. (*Wireless World*, vol. 66, pp. 67–68; February, 1960.) Comparison of the condition of the ionosphere in 1959 with that of previous years, and deduction of the probable state for 1960.

551.510.536:550.385 1225
Global Hydromagnetic Wave Ducts in the Exosphere—H. A. Bomke, W. J. Ramn, S. Goldblatt, and V. Klemas. (*Nature*, vol. 185, pp. 299–300; January 30, 1960.) Magnetic-field perturbations originating from a high-altitude explosion have been observed at a number of stations. An analysis of results indicates that hydromagnetic waves at high altitudes travel along great-circle paths in ducts which are concentric shells about the earth. "Slow" and "fast" signals are identified respectively with transverse and longitudinal hydromagnetic wave modes.

551.594.5:621.396.96 1226
Aurora-Like Radar Echoes Observed from 17° Latitude—R. B. Dyce, L. T. Dolphin, R. L. Leadabrand, and R. A. Long. (*J. Geophys. Res.*, vol. 64, pp. 1815–1818; November, 1959.) A note on anomalous echoes observed regularly at 32 and 140 mc by a shipborne radar located in British West Indies.

551.594.6 1227
Correlation of Audio-Frequency Electromagnetic Radiation with Auroral Zone Micropulsations—J. Aarons, G. Gustafsson and A. Egeland. (*Nature*, vol. 185, pp. 148–151; January 16, 1960.) A spectrum analysis in the range 10 cps–10 kc has been made of recordings obtained during three one-month periods near Kiruna, Sweden. There is excellent correlation between auroral-zone micropulsations and EM radiation. Two distinct frequency bands have been identified.

551.594.6:550.385.4 1228
Rare Hiss, Earth Currents and Micropulsations on November 27, 1959—E. M. Wescott, J. H. Pope, D. O. Dyer, and W. H. Campbell. (*Nature*, vol. 185, p. 231; January 23, 1960.) Brief report of hiss and micropulsations associated with a sudden commencement at 2351 GMT observed at College, Alaska.

551.594.6:621.396.663 1229
Direction Findings on Whistlers—J. M. Watts. (*J. Geophys. Res.*, vol. 64, pp. 2029–2030; November, 1959.) The use of a crossed-loop type of direction finder and the information on whistlers to be obtained from it are described.

551.510.535 1230
The Magneto-Ionic Theory and Its Application to the Ionosphere [Book Review]—J. A. Ratcliffe, Cambridge University Press, Eng. 206 pp.; 1959. (*J. Atmos. Terr. Phys.*, vol. 16, p. 398; November, 1959.)

LOCATION AND AIDS TO NAVIGATION

621.396.933.2 1231
Some Factors in the Design of V.H.F. Automatic Direction Finders—S. A. W. Jolliffe. (*Marconi Rev.*, vol. 22, pp. 168–198; 4th Quarter, 1959.) Basic systems are analyzed and some of the more interesting design features of a preferred system are discussed in detail. The performance figures of a typical automatic direction finder are given.

621.396.933.2 1232
Operational Applications of V.H.F. Direction Finders—S. A. W. Jolliffe. (*Marconi Rev.*, vol. 22, pp. 199–214; 4th Quarter, 1959.) Factors limiting the accuracy of ground-based systems are discussed and comparisons are made in terms of technical performance and capital and operating costs.

621.396.933.2 1233
The Marconi Automatic Plotter—D. W. G. Byatt. (*Marconi Rev.*, vol. 22, pp. 215–224; 4th Quarter, 1959.) The plotter described is for use with automatic direction finders operating on aircraft in the VHF and UHF band. Provision is made for up to six bearing traces.

621.396.933.2 1234
Bearing Errors in Medium-Frequency Automatic Direction Finders—R. W. Sharples. (*Marconi Rev.*, vol. 22, pp. 225–233; 4th Quarter, 1959.) Errors due to spurious inputs to

the loop-drive motor and to lack of sensitivity in the servo system are analyzed.

621.396.933.2:621.317.7 1235

A Method of Providing Test Signals of Calculable Strength for Airborne Radio Direction Finders—R. W. Sharples. (*Marconi Rev.*, vol. 22, pp. 234–239; 4th Quarter, 1959.) A method is described in which the loop antenna is placed in a magnetic field of known strength in a screened enclosure. Mreasurements are within ±0.5 db of the calculated value. Practical results show that the enclosure may be reduced to a size suitable for portable use without loss of accuracy.

621.396.934 1236

Beam Riding—P. Cave. (*Wireless World*, vol. 66, pp. 71–74; February, 1960.) A detailed introduction to missile guidance systems based on the principle of following a beam of radio signals.

621.396.96:551.594.5 1237

Aurora-Like Radar Echoes Observed from 17° Latitude—Dyce, Dolphin, Leadabrand, and Long. (*See* 1226.)

621.396.96:621.273.837.3 1238

Duplexing a Solid-State Ruby Maser in an X-Band Radar System—F. E. Goodwin. (PROC. IRE, vol. 48, p. 113; January, 1960.) Description of a ferrite TR-switch which attenuates the transmitter pulse by 30 db over a frequency band of 120 mc.

621.396.96.089.6:523.164.32 1239

How Solar Noise Calibrates Radars—J. A. Kuecken. (*Electronics*, vol. 32, pp. 44–45; December 25, 1959.) The sun is used as a distant source to check the relation of the beam direction to the aiming angle of C-band radar antennas. Accuracies within 0.03 degree have been obtained.

621.396.962.3 1240

Introduction to Monopulse [Book Review] —D. R. Rhodes. McGraw-Hill Book Co., Inc., New York, London, and Toronto, 119 pp.; 1959. (*Proc. Phys. Soc.*, vol. 74, p. 800; December 1, 1959.) Deals with a radar system of location based on simultaneous radiation lobes instead of sequentially emitted beams.

MATERIALS AND SUBSIDIARY TECHNIQUES

535.215:535.37:621.38 1241

Solid-State Optoelectronics—E. E. Loebner. (*RCA Rev.*, vol. 20, pp. 715–743; December, 1959.) Photoelectric and luminescence phenomena are classified and explained. The technology of opto-electronic devices, *i.e.* those having mixed optical and electrical signal and power access, is described. Application to logic nets and computer components is treated in detail, and the synthesis of picture-processing panels and computer systems is considered.

535.215:537.311.33 1242

Depletion-Layer Photoeffects in Semiconductors—W. W. Gärtner. (*Phys. Rev.*, vol. 116, pp. 84–87; October 1, 1959.) A theory of photoconduction through the reverse-biased *p-n* junction in semiconductors is developed; the treatment leads to a voltage dependence for the photocurrent and its spectral distribution. Transit-time effects occurring at high modulation frequencies are analyzed.

535.215:[546.32'863+546.36'863 1243

Structure in the Energy Distribution of Photoelectrons from K$_3$Sb and CaS$_3$b—E. A. Taft and H. R. Philipp. (*Phys. Rev.*, vol. 115, pp. 1583–1586; September 15, 1959.) Peaks in energy distribution seem to correlate with peaks in the optical absorption. A lower limit for the electron affinity of the crystal may be deduced assuming that the effects arise directly from structure in the state-density of the valence band.

535.215:546.48'221 1244

On the Problem of Measuring the Diffusion Length of Holes in Cadmium Sulphide—N. A. Vitovskiĭ and P. I. Maleev. (*Fiz. Tverdogo Tela*, vol. 1, pp. 984–985; June, 1959.) The diffusion length was determined from the variation with applied voltage of the amplitude of pulses produced by α-particle irradiation. Measurements on three single-crystal samples gave values for diffusion length from 1.3 to 3.2 μ.

535.215:546.48'221 1245

Dependence of the Hole Ionization Energy of Imperfections in Cadmium Sulphide on the Impurity Concentration—R. H. Bube and A. B. Dreeben. (*Phys. Rev.*, vol. 115, pp. 1578–1582; September 15, 1959.) Photoconductivity measurements have been made in a series of CdS-Ga, Cu powders. Results are analogous to other recent observations of small hole ionization energies in CdS and CdSe crystals.

535.215:546.48'221 1246

The Achievement of Maximum Photoconductivity Performance in Cadmium Sulphide Crystals—R. H. Bube and L. A. Barton. (*RCA Rev.*, vol. 20, pp. 564-598; December, 1959.) Attempts to improve the photoconductivity performance of CdS crystals by reducing trapping-center concentration are described. This could be successfully accomplished by a) producing slight deviations from stoichiometry during growth, or b) incorporating a trace of donor impurity.

535.215:546.48'221 1247

Quenching Effect of the Photoconductivity Decay in CdS—M. Kikuchi and S. Iizima. (*J. Phys. Soc. Japan*, vol. 14, p. 856; June, 1959.) Decay of the photocurrent in a CdS rectifying cell (*see* 1258 below) may be accelerated by reducing the bias voltage to zero for 10 seconds.

535.215:546.48'221'241 1248

Preparation of Mixed CdS-CdTe Single Crystals and some of their Properties—I. Vitrikhovskiĭ and I. B. Mizetskaya. (*Fiz. Tverdogo Tela*, vol. 1, pp. 996–999; June, 1959.)

535.215:546.48'241 1249

Phase Equilibria and Semiconducting Properties of Cadmium Telluride—D. de Nobel. (*Philips Res. Rep.*, vol. 14, pp. 361–399 and 430–492; August and October, 1959.) 47 references.

535.215:546.681'241 1250

Photoconductivity of Gallium Selenide Crystals—R. H. Bube and E. L. Lind. (*Phys. Rev.*, vol. 115, pp. 1159–1164; September, 1959.)

535.215:546.817'221 1251

Preparation of Load Sulphide Photoresistances by Chemical Deposition—R. Ya. Berlaga, F. T. Novik, and L. P. Strakhov. (*Fiz. Tverdogo Tela*, vol. 1, pp. 995–996; June, 1959.) Brief note on the preparation of PbS films at room temperature by treatment of Pb(OH)$_2$ with thiourea solution.

535.215:546.863'231 1252

Conductivity and Photoconductivity of Antimony Triselenide—B. T. Kolomiets, V. M. Lyubin, and D. V. Tarkhin. (*Fiz. Tverdogo Tela*, vol. 1, pp. 899–902; June, 1959.)

535.215:546.863'231 1253

Photoconductivity of Sb$_2$Se$_3$—B. T. Kolomiets and A. Kh. Zeĭnally. (*Fiz. Tverdogo Tela*, vol. 1, pp. 979–980; June, 1959.) Experimental data show the photosensitivity of single crystals to be much greater than that of polycrystalline material.

535.215:621.311.69 1254

The Photovoltaic Effect and its Utilization—P. Rappaport. (*RCA Rev.*, vol. 20, pp. 373–397; September, 1959.) A review of the theory of the photovoltaic effect and of its applications to solar energy conversion. Operating characteristics and conversion efficiencies of a number of materials including Si, GaAs, InP, and CdS are given and the high-voltage photovoltaic effect obtained with evaporated CdTe films is described.

535.37 1255

Electroluminescence of Polycrystallites—S. Larach and R. E. Schrader. (*RCA Rev.*, vol. 20, pp. 532–563; December, 1959.) General discussion of luminescence, and, in particular, various effects of electroluminescence.

535.37:061.3(47) 1256

Transactions of the 7th Conference on Luminescence (Crystal Phosphors)—(*Izv. Ak. Nauk S.S.S.R.*, vol. 23, pp. 1278–1400; November, 1959.) Texts are given of 25 papers presented at the conference in Moscow, June 26–July 3, 1958.

535.376:534.231–8 1257

The Electroluminescent Panel in an Ultrasonic Field—P. Greguss and J. Weiszburg. (*Acustica*, vol. 9, no. 3, pp. 183–184; 1959.) A note of an experiment in which a panel of ZnS-Cu,Pb powder with a filling material of high dielectric constant gave a yellow luminescence under ultrasonic irradiation.

535.376:546.48'221 1258

Avalanche Electroluminescence in CdS Single Crystal—M. Kikuchi and S. Īizima. (*J. Phys. Soc. Japan*, vol. 14, p. 852; June, 1959.) A CdS rectifying cell is described. When the forward voltage is increased to between 25 and 50 volts, the forward current increases rapidly and light is emitted. Characteristic curves for the cell are given.

537.227 1259

Analogy of a Ferroelectric Phenomenon to a Ferromagnetic Phenomenon: Attenuation of Ferroelectric Hysteresis by Orthogonal Polarization—Y. Angel and J. Bonnefous. (*Compt. rend.*, vol. 249, pp. 508–510; July 27, 1959.) Measurements have been made on ferroelectric plates of TiO$_3$Ba$_x$Sr$_{1-x}$ ceramic about 1-mm thick subjected to a direct longitudinal and alternating transverse electric field. Results analogous to those obtained with ferrite samples in orthogonal magnetic fields [3244 of 1959 (Angel and Boutry)] are reported.

537.227 1260

Dielectric Property of Triglycine Sulphate Single Crystal at 9000 Mc/s Region—A. Nishioka and M. Takeuchi. (*J. Phys. Soc. Japan*, vol. 14, p. 971; July, 1959.) Measurements at room temperature in the ferroelectric *b* axis give a dielectric constant of 19.7 ±0.2 and a loss tangent of 0.043 ±0.002.

537.227 1261

Action of an Electric Field on the Dielectric Properties of Glycine Sulphate—J. Chapelle and L. Faurel. (*Compt. rend.*, vol. 249, pp. 378–380; July 20, 1959.) Polarization P is related to the electric field E along the binary axis of a crystal in accordance with an equation of the form $E=aP+bP^3+cP^5$.

537.227 1262

A Few Quarternary Systems of Perovskite —Type A^{2+}B^{4+}O$_3$ Solid Solutions—T. Ikeda. (*J. Phys. Soc. Japan*, vol. 14, pp. 1286–1294; October, 1959.) Structural and dielectric properties of the systems (Sr-Pb)(Ti-Zr)O_3 and (Ba-Pb)(Ti-Sn)O_3.

537.227 1263

New Ferroelectrics of Complex Composition: Part 3—Pb_2MgWO_6, $Pb_3Fe_2WO_9$ and Pb_2FeTaO_6—G. A. Smolenskiĭ, A. I. Agranovskaya and V. A. Isupov. (*Fiz. Tverdogo Tela*, vol. 1, pp. 988–990; June, 1959.) A note of measurements of permittivity and loss tangent in the temperature range −200°C to +300°C.

537.227 1264

Dielectric Polarization of Solid Solutions in the System (Ba,Sr)(Ta,Nb)$_2$O$_3$—G. A. Smolenskiĭ, V. A. Isupov, and A. I. Agranovskaya. (*Fiz. Tverdogo Tela*, vol. 1, pp. 992–995; June, 1959.) Investigation of the temperature dependence of permittivity and loss tangent in the range −160°C to +160°C at a frequency of 1 kc.

537.227/.228.1:546.33.882.5 1265

Dielectric Polarization and Piezoelectric Properties of certain Ferroelectric Solid Solutions based on Sodium Niobate—V. A. Isupov and V. I. Kosyakov. (*Fiz. Tverdogo Tela*, vol.1, No. 6, pp. 929–934; June, 1959.)

537.227:546.431'824–31 1266

Further Experiments on the Sidewise Motion of 180° Domain Walls in $BaTiO_3$—R. C. Miller and A. Savage. (*Phys. Rev.*, vol. 115, pp. 1176–1180; September, 1959.) The electric-field dependence of the velocity of the sidewise motion is given by v_∞ exp $(-\delta/E)$ where δ varies very slightly with applied field. The measurements have been made over the velocity range 10^{-7}–10^{2} cm-sec^{-1}.

537.227:621.318.57 1267

Switching Mechanism in Triglycine Sulphate and other Ferroelectrics—E. Fatuzzo and W. J. Merz. (*Phys. Rev.*, vol. 116, pp. 61–68; October 1, 1959.) A description of the switching properties as a function of applied electric field, temperature, and sample thickness. A proposed model is treated mathematically and results are compared with experimental data.

537.228.1:621.382.2 1268

Piezoelectric Effect in a Rectifying Contact of Semiconductor—T. Tanaka and H. Kawamura. (*J. Phys. Soc. Japan*, vol. 14, p. 1455; October, 1959.) Results of experiments with a selenium rectifier and with a Ge *p-n* junction.

537.311.33 1269

A Statistical Theory of the Electrical Conductivity of Semiconductors: Part 1—M. I. Klinger. (*Fiz. Tverdogo Tela*, vol. 1, pp. 861–872; June, 1959.) A general expression obtained by a density-matrix method is used to derive a formula for conductivity in the case of weak electron-phonon interaction. This new formula is examined and applied to the scattering of electrons by polarized phonons.

537.311.33 1270

Rate of Diffusion-Limited Annihilation of Excess Vacancies—P. Penning. (*Philips Res. Rep.*, vol. 14, pp. 337–345; August, 1959.) "The rate of removal and the spatial distribution of excess vacancies are calculated for the case where the transport to vacancy sinks takes place by diffusion and where dislocations in the volume of the sample, the surface of the sample or both may act as sinks." See 2458 of 1958.

537.311.33:537.32.083 1271

On the Problem of Measuring Thermoelectric Properties of Semiconductors—M. A. Kaganov, I. S. Lisker, and I. G. Mushkin. (*Fiz. Tverdogo Tela*, vol. 1, pp. 988–990; June, 1959.) A correction factor for heat loss applied to a formula of Harman (*J. Appl. Phys.*, vol. 29, pp. 1373–1374; September, 1958) is shown to be independent of the current intensity.

537.311.33:[546.28+546.289 1272

Crystalline Imperfections and 1/*f* Noise—J. J. Brophy. (*Phys. Rev.*, vol. 115, pp. 1122–1125; September 1, 1959.) Experimental results indicate that increasing the crystalline imperfection densities in Ge and Si causes the 1/*f* noise level to decrease through reduction in minority-carrier lifetime.

537.311.33:546.28 1273

Surface Recombination of Silicon—H. U. Harten. (*Philips Res. Rep.*, vol. 14, pp. 346–360; August, 1959.) Extension of investigations described ealier (560 of February).

537.311.33:546.28 1274

Ionized-Impurity Scattering Mobility of Electrons in Silicon—D. Long and J. Myers. (*Phys. Rev.*, vol. 115, pp. 1107–1118; September, 1959.) The temperature dependence of electron mobility has been determined between 30° and 100°K for *n*-type samples of varying impurity content by combining data from electrical resistivity and Hall-effect measurements. The dependence is shown to be consistent with the Brooks-Herring scattering formula when the Born approximation is valid.

537.311.33:546.28 1275

Hall Effect and Impurity Levels in Phosphorus-Doped Silicon—D. Long and J. Myers. (*Phys. Rev.*, vol. 115, pp. 1119–1121; September 1, 1949.) The measured splitting of the (1*s*) energy level agreed well with the value deduced theoretically from the Kohn-Luttinger model.

537.311.33:546.28 1276

Effects of Heat Treatment upon the Electrical Properties of Silicon—Y. Matukura. (*J. Phys. Soc. Japan*, vol. 14, pp. 918–923; July, 1959.) A report of observations of changes in carrier density and minority-carrier lifetime in pulled crystals of Si over the temperature range 400°–1200°C.

537.311.33:546.28 1277

Influence of an External Electric Field on the Surface Recombination and Capacitor Photo-E.M.F. of *n*-Type Silicon—O. V. Snitko. (*Fiz. Tverdogo Tela*, vol. 1. pp. 980–983; June, 1959.) Measurements were made on five single-crystal samples of thickness $\sim 3\times10^{-2}$ cm. Graphs show the dependence of the dark conductivity and surface recombination velocity on the surface charge.

537.311.33:546.28 1278

Certain Improvements in the Method of Preparing Pure Silicon by Thermal Decomposition of Silane—Ya. E. Pokrovskiĭ, S. I. Kleshchevnikova, and E. I. Rumyantseva. (*Fiz. Tverdogo Tela*, vol. 1, pp. 999–1001; June, 1959.) An improved version of the apparatus described earlier [2780 of 1958 (Kleshchevnikova, *et al.*)].

537.311.33:546.28:539.12.04 1279

Infrared Absorption of Silicon of High Resistivity containing Radiation Defects—V. S. Vavilov, A. F. Plotnikov, and G. V. Zakhvatkin. (*Fiz. Tverdogo Tela*, vol. 1, pp. 976–979; June, 1959.)

537.311.33:[546.289+546.682'86 1280

On the Delayed Yield n Germanium and Indium Antimonide—D. Dew-Hughes and G. E. Brock. (*J. Appl. Phys.*, vol. 30, pp. 2020–2021; December, 1959.) The delay time for plastic yielding may be associated with impurity locking of dislocations.

537.311.33:546.289 1281

Kinetics of the Interchange of Electrons between the Surface and the Bulk of Germanium—A. E. Yunovich. (*Fiz. Tverdogo Tela*, vol. 1, pp. 908–912; June, 1959.) An equation is derived for the dependence of the field effect on frequency in the range 10^2–10^6 cps. The relaxation time of the field effect coincides with the effective lifetime of nonequilibrium charge carriers. The dependence of the effective mobility on frequency is shown for *p*- and *n*-type samples in different atmospheres.

537.311.33:546.289 1282

Studies of Vacancies in Dislocation-Free Ge Crystals—A. G. Tweet. (*J. Appl. Phys.*, vol. 30, pp. 2002–2010; December, 1959.) Experiments carried out to determine the number of vacancies incorporated into a Ge crystal during growth are described.

537.311.33:546.289 1283

Dislocation Acceptor Levels in Germanium—R. K. Mueller. (*J. Appl. Phys.*, vol. 30, pp. 2015–2016; December, 1959.) A dislocation-band model is described which gives good agreement between acceptor levels observed in grain boundaries and those derived from carrier depletion data.

537.311.33:546.289 1284

The Field Dependence of the Mobility of Electrons in *n*-Germanium—H. Sato. (*J. Phys. Soc. Japan*, vol. 14, pp. 1275–1285; October, 1959.) A theory is developed, based on an assumed momentum distribution, which indicates an appreciable energy loss of electrons due to acoustic-mode scattering at very high field strengths. Improved agreement with experimental data is obtained.

537.311.33:546.289 1285

Mechanism of the Increasing Long-Term Changes of the Field Effect—V. I. Lyashenko and N. S. Chernaya. (*Fiz. Tverdogo Tela*, vol. 1, pp. 878–885; June, 1959.) Investigation of *p*-type Ge showed a decrease of the screening of the field with time. This is related to the conductor.

531.311.33:546.289 1286

Extraction of Copper and Nickel from Germanium—K. P. Tissen. (*Fiz. Tverdogo Tela*, vol. 1, pp. 1001–1003; June, 1959.)

537.311.33:546.289:538.632 1287

Dependence of the Hall Effect on Pressure in *p*-Type Germanium of 50-Ohm cm Resistivity—A. I. Likhter. (*Fiz. Tverdogo Tela*, vol. 1, pp. 895–898; June, 1959.)

537.311.33:546.289:548.5 1288

Investigation of the Oriented Growth of Germanium on a Fluorite Single Crystal—J. Marucchi and N. Nifontoff. (*Compt. rend.*, vol. 249, pp. 435–437; July 20, 1959.)

537.311.33:546.289:548.5 1289

Dendritic Growth of Germanium Crystals—A. I. Bennett and R. L. Longini. (*Phys. Rev.*, vol. 116, pp. 53–61; October 1, 1959.) A general description of the experimental technique and basic theory.

537.311.33:546.47–31 1290

The Diffusion of Excess Zinc in Zinc Oxide Crystals (Investigations of Electrical Conductivity)—R. Pohl. (*Z. Phys.*, vol. 155, pp. 120–128; May 6, 1959.) Conductivity changes in ZnO first heated in Zn vapor and subsequently in air are measured as a function of time. The effects noted are interpreted on the basis of diffusion processes.

537.311.33:546.57'24 1291

Galvano- and Thermo-magnetic Effects in α-Ag_2Te—S. Miyatani and I. Yokota. (*J. Phys. Soc. Japan*, vol. 14, pp. 750–754; June, 1959.) Nernst coefficient, magnetoresistance and magnetothermoelectric power of α-Ag_2Te have been measured as functions of the EMF of a galvanic cell Ag/AgI/Ag_2Te/Pt. See 3532 of 1958 (Miyatani).

537.311.33:546.681'19:538.639 1292

The Nernst-Ettingshausen Effect in Gallium Arsenide—O. V. Emel'yanenko and D. N. Nasledov. (*Fiz. Tverdogo Tela*, vol. 1, pp. 985–988; June, 1959.) Results of an experimental investigation of GaAs are in qualitative agreement with the theory of thermomagnetic effects and indicate the prevalence of scattering on impurity ions in nondegenerate and degenerate *n*-type GaAs at temperatures less than 300° to 400°K.

537.311.33:546.682'19:539.12.04 1293

Electron Irradiation of Indium Arsenide—L. K. Aukerman. (*Phys. Rev.*, vol. 115, pp. 1133–1135; September 1, 1959.) During irradiation with 4.5-mev electrons the carrier concentration in *n*-type InAs increases; this increase is followed to a carrier concentration $10^{17}/cm^3$. Under the same conditions the concentration in *p*-type InAs decreases.

537.311.33:546.682'682'86 1294

Equilibrium Solid Solutions in the InSb-GaSb System—V. I. Ivanov-Omskiĭ and B. T. Kolomiets. (*Fiz. Tverdogo Tela*, vol. 1, pp. 913–918; June, 1959.)

537.311.33:546.682'86 1295

Preparation and Electrical Properties of Alloyed *p-n* Junctions of InSb—C. A. Lee and G. Kaminsky. (*J. Appl. Phys.*, vol. 30, pp. 2021–2022; December, 1959.) Techniques for producing these junctions are described and some characteristics are given. The high electron mobility of InSb should have advantages in some applications.

537.311.33:546.682'86 1296

Electrical Properties of *n*-Type InSb in High Electric Field at 77°K—Y. Kanai. (*J. Phys. Soc. Japan*, vol. 14, pp. 1302–1308; October, 1959.) At high fields, the resistivity and Hall coefficient were found to decrease rapidly with increasing field. At the same time the Hall mobility decreased and the drift velocity passed through a maximum value.

537.311.33:546.682'86 1297

Magnetic Susceptibility of InSb—R. Bowers and Y. Yafet. (*Phys. Rev.*, vol. 115, pp. 1165–1172; September 1, 1959.) The observed susceptibility increases with increasing carrier density at low densities and decreases at high densities. The results depart from that expected from a parabolic conduction band but are consistent with Kane's band-structure calculation (3156 of 1958).

537.311.33:546.682'86:537.312.8 1298

On the Anomalous Magnetoresistance Effect in *n*-InSb—W. Sasaki and C. Yamanouchi. (*J. Phys. Soc. Japan*, vol. 14, p. 849; June, 1959.) The oscillatory magnetoresistance effect observed by Broom (2149 of 1958) at liquid-helium temperature is shown to be caused by the same mechanism as the de Haas-van Alphen effect. An assumed value of 0.015 *m* for the electron mass fits the experimental data given.

537.311.33:546.682'86:539.12.04 1299

Electron Irradiation of Indium Antimonide—L. W. Aukerman. (*Phys. Rev.*, vol. 115, pp. 1125–1132; September 1, 1959.) Experiments carried out on single crystals of *n*- and *p*-type InSb bombarded with 4.5-Mev electrons at 80° and 200°K are reported. Samples bombarded at 80°K showed three regions of rapid annealing as measured by the change in carrier concentration; the first two regions lay between 80° and 200°K, the third near room temperature.

537.311.33:546.817'241 1300

On Galvanomagnetic Effects in *p*-Type Crystals of PbTe—K. Shogenji. (*J. Phys. Soc. Japan*, vol. 14, pp. 1360–1371; October, 1959.) Measurements at 90°K indicate an electronic band structure represented by $\{111\}$ energy spheroids, presumably prolate with a mass ratio of 0.3.

537.311.33:546.873'241 1301

The Sintering of Bismuth Telluride—W. R. George, R. Sharples, and J. E. Thompson. (*Proc. Phys. Soc.*, vol. 74, pp. 768–770; December 1, 1959.) Samples of $BiTe_3$ doped with iodine were sintered at various temperatures; thermoelectric power varied with sintering temperature, and showed changes in sign.

537.311.62:546.87 1302

Anomalous Skin Effect in Bismuth—G. E. Smith. (*Phys. Rev.*, vol. 115, pp. 1561–1568; September 15, 1959.) Surface resistance measurements have been made at 23.5 kmc on plane surfaces of single-crystal Bi at 2°K as a function of orientation.

537.324:537.311.33 1303

Effect of Impurity Scattering on the Figure of Merit of Thermoelectric Materials—R. W. Ure, Jr. (*J. Appl. Phys.*, vol. 30, pp. 1922–1924; December, 1959.) "The thermoelectric figure of merit $z=a^2/\rho k$ is calculated for an extrinsic semiconductor with mixed acoustic-mode lattice scattering and ionized-impurity scattering. The result is compared to the value for pure acoustic-mode scattering. As the amount of ionized-impurity scattering is increased, the figure of merit increases by less than 10% and then falls slowly."

537.533.8 1304

Variation of the Coefficient of Secondary Electron Emission of some Metals with respect to the Energy of Incident Ions—P. Cousinié, N. Colombié, C. Fert, and R. Simon. (*Compt. rend.*, vol. 249, pp. 387–389; June 20, 1959.) Experimental results have been obtained for A^+ and H^+ ions with energies 5–40 kev.

538.221 1305

Theoretical Approach to the Asymmetrical Magnetization Curve—A. Aharoni, E. H. Frei, S. Shtrikman. (*J. Appl. Phys.*, vol. 30, pp. 1956–1961; December, 1959.) A calculation is made of the magnetization curve of an infinite cylinder of Co particles in a CoO shell; results are also given for an infinite slab.

538.221 1306

Nuclear Orientation and the Hyperfine Structure Coupling in Cobalt Metal—M. A. Grace, C. E. Johnson, N. Kurti, R. G. Scurlock, and R. T. Taylor. (*Phil. Mag.*, vol. 4, pp. 948–956; August, 1959.) The hyperfine structure coupling, represented as an effective magnetic field $H_{\rm eff}$ at the nucleus, is given by $H_{\rm eff}=193\pm20$ kg.

538.221 1307

Effect of Crystallographic Twins on the D.C. and A.C. Properties of Nickel-Iron-Alloys—J. E. Thompson. (*Brit. J. Appl. Phys.*, vol. 10, pp. 511–516; December 1959.) Deleterious effects on the magnetic properties of 50 per cent Ni-Fe alloys due to twinning during the annealing process are discussed.

538.221:538.569.4 1308

Dipolar Line Broadening and Enhanced Pseudo-dipolar Moments—R. L. White. (*Phys. Rev.*, vol. 115, pp. 1519–1520; September 15, 1959.) The assumption of a strongly enhanced pseudo-dipolar moment in certain ferrimagnetic and antiferromagnetic materials is shown to be incompatible with the paramagnetic-resonance line widths in these materials.

538.221:538.569.4 1309

Note on the Saturation of the Main Resonance in Ferromagnetics—H. Suhl. (*J. Appl. Phys.*, vol. 30, pp. 1961–1964; December, 1959.) "The course of χ" at resonance *versus* applied power is traced for various ratios of intrinsic to scattering line widths. It is assumed that the line-width contribution from thermal spin-wave agitation is negligible."

538.221:538.632 1310

Effective Field in the Ordinary Hall Effect in Ferromagnetics—E. Tatsumoto and T. Okamoto. (*J. Phys. Soc. Japan*, vol. 14, pp. 976–977; July, 1959.) The effective field is shown to be the magnetizing field. *See* also 1311 below.

538.221:538.632 1311

Extraordinary Hall Effect in Silicon-Iron Single Crystals—E. Tatsumoto and T. Okamoto. (*J. Phys. Soc. Japan*, vol. 14, pp. 975–976; July, 1959.) A method is described for obtaining the extraordinary Hall coefficient from probe measurements of Hall resistivity at the edge and about 1.5 mm from the edge of the specimen. The effect is found to be isotropic.

538.221:539.23 1312

Magnetic Anisotropy of Evaporated Films Formed in Magnetic Field—M. Takahashi, D. Watanabe, T. Sasagawa, H. Saito, and S. Ogawa. (*J. Phys. Soc. Japan*, vol. 14, pp. 1459–1460; October, 1959.) Quantitative measurements of the anisotropy of Fe, Co, Ni and Ni-Fe films.

538.221:539.23:538.632 1313

New Experimental Results concerning the Hall Effect in Thin Films of Nickel—A. Colombani and G. Goureaux. (*Compt. rend.*, vol. 249, pp. 381–383; July 20, 1959.)

538.221:539.23:538.632 1314

The Hall Constants of Thin Films of Nickel—G. Goureaux and A. Colombani. (*Compt. rend.*, vol. 249, pp. 511–513; July 27, 1959.)

538.221:539.23:621.318.57 1315

Isolation of Rotational Reversal in Ferromagnetic Films—A. L. Hanzel and R. L. Conger. (*J. Appl. Phys.*, vol. 30, pp. 1932–1936; December, 1959.) The relative contributions of wall motion and domain rotation to the magnetization reversal process in thin ferromagnetic films are investigated experimentally.

538.221:621.317.42 1316

Measurement of the Gradient of the Magnetic Field at the Boundary Surface of a Magnetic Body—S. Yamaguchi. (*Z. Metallk.*, vol. 50, pp. 721–722; December, 1959.) A gradient of 9×10^4 grams/cm was measured by an electron-diffraction method at the edge of a Ni film containing nickel oxide.

538.221:621.318.134 1317

The Frequency and Temperature Characteristics of Complex Permeability of High-Permeability Ferrites—D. Köhler. (*Arch. elekt. Übertragung*, vol. 13, pp. 1–12; January, 1959.) The results of measurements on Mn-Zn and Ni-Zn ferrites are analyzed and interpreted on the basis of existing theories. 36 references.

538.221:621.318.134 1318

Electric Resistance and Cation Distribution of Fe-Mn Ferrite System—Z. Funatogawa, N. Miyata, and S. Usami. (*J. Phys. Soc. Japan*, vol. 14, p. 854; June, 1959.)

538.221:621.318.134:537.311.3 1319

The Electrical Resistivity of Oxygen-Deficient Nickel Ferrite—R. Parker and H. Lord.

(*Proc. Phys. Soc.*, vol. 74, pp. 793–795; December 1, 1959.) Results of measurements are interpreted with reference to different "types" of conduction. See also 1220 of 1959 (Parker).

538.221:621.318.134:538.569.4 1320

High-Power Effects in Ferrite Devices—P. E. Seiden and H. J. Shaw. (PROC. IRE, vol. 48, p. 122; January, 1960.) Profile line-widths and the threshold for onset of decrease in susceptibility have been measured for ferrite samples.

538.221:621.318.134:538.569.4 1321

Spin Temperature and High-Power Effects in Ferrimagnets—M. T. Weiss. (*J. Appl. Phys.*, vol. 30, p. 2014; December, 1959.) Experimental results for Mn ferrite and Y-Fe garnet seem to confirm the hypothesis that high microwave power levels tend to increase the spin temperature and that this change is effective in changing the *g* factor.

538.221:621.318.134:538.569.4 1322

Theory of Ferromagnetic Resonance in Rare-Earth Garnets: Part 1—*g* Values—C. Kittel. (*Phys. Rev.*, vol. 115, pp. 1587–1590; September 15, 1959.) The *g* values observed in resonance experiments are analyzed. General features of experimental results are reproduced fairly well by calculated curves.

538.221:621.318.134:538.569.4 1323

Ferrimagnetic Resonance Line Width in Polycrystalline $Y_3Fe_{5-x}In_xO_{12}$—T. Miyadai, Y. Schichijo, and I. Tsubokawa. (*J. Phys. Soc. Japan*, vol. 14, p. 853; June, 1959.)

538.221:621.318.134:538.632 1324

Hall-Effect Measurement on Magnetite and a Nickel Ferrite with Excess Iron—W. Mann. [*Ann. Phys.* (*Lpz.*), vol. 3, pp. 122–124; March 24, 1959.] Measurements were made on Fe_3O_4 and $(Fe_2O_3)_{0.65}(NiO)_{0.35}$ using a dc compensation method.

538.221:621.318.57 1325

A Contribution to the Study of Switching in a Ferromagnetic Core Fed by a Perfect Current Source—C. Durante and J. Lailheugue. (*Compt. rend.*, vol. 249, pp. 917–918; August 31, 1959.) A discrepancy between the theoretical and experimental results is explained. See also 253 of January (Durante).

538.222 1326

The Ratio of the Isolated and the Adiabatic Susceptibility of Paramagnetic Crystals—W. J. Caspers. (*Physica*, vol. 25, pp. 43–49; January, 1959.)

538.222:538.569.4 1327

Theory of the Nuclear Magnetic Resonance Shift in Paramagnetic Crystals—F. Keffer, T. Oguchi, W. O'Sullivan, and J. Yamashita. (*Phys. Rev.*, vol. 115, pp. 1553–1561; September 15, 1959.) A theoretical study is made of the shift of the F^{19} nuclear resonance in paramagnetic and antiferromagnetic MnF_2 observed by Shulman and Jaccarino (see *ibid.*, vol. 108, pp. 1219–1231; December 1, 1957.) Results are in reasonable agreement with experiment.

538.222:538.569.4 1328

Self-Absorption and Trapping of Sharp-Line Resonance Radiation in Ruby—F. Varsanyi, D. L. Wood, and A. L. Schawlow. (*Phys. Rev. Lett.*, vol. 3, pp. 544–545; December 15, 1959.)

538.222:538.569.4 1329

Optical Detection of Paramagnetic Resonance in an Excited State of Cr^{3+} in Al_2O_3—S. Geschwind, R. J. Collins, and A. L. Schawlow. (*Phys. Rev. Lett.*, vol. 3, pp. 545–548; December 15, 1959.)

538.222:538.569.4 1330

Optical Detection of Paramagnetic Resonance in Crystals at Low Temperatures—J. Brossel, S. Geschwind, and A. L. Schawlow. (*Phys. Rev. Lett.*, vol. 3, pp. 548–549; December 15, 1959.)

538.222:538.569.4:534.2–8 1331

Saturation of Paramagnetic Spins by 13-Mc/s Ultrasonic Phonons—R. D. Mattuck and M. W. P. Strandberg. (*Phys. Rev. Lett.*, vol. 3, pp. 550–551; December 15, 1959.) Experiments with ruby, Cr-doped MgO, and quartz are reported.

539.2:538.22 1332

Energy Levels for Rare-Earth Ions Subject both to Exchange and Crystalline Fields—R. L. White and J. P. Andelin, Jr. (*Phys. Rev.*, vol. 115, pp. 1435–1439; September 15, 1959.) The term splitting is calculated for the lowest *J* state of the rare-earth ions samarium to ytterbium, subjected simultaneously to exchange and crystalline fields. The crystalline field is taken to be cubic and the calculation is carried out for the magnetic axis in the [100] and [111] directions. Application to the rare-earth garnets is discussed.

539.2:548.0 1333

Simplified LCAO Method for Zincblende, Wurtzite, and Mixed Crystal Structures—J. L. Birman. (*Phys. Rev.*, vol. 115, p. 1493–1505; September 15, 1959.) Qualitative comparison of energy bands in the structures.

621.315.61.004.6 1334

Life of Technical Dielectrics Operating in High-Frequency Fields—A. T. Alad'ev. (*Fiz. Tverdogo Tela*, vol. 1, pp. 935–938; June, 1959.) An expression is derived showing the dependence of useful life on electric field intensity and frequency, and on the dimensions and distribution of pores in the dielectric. This equation applies in the range from several seconds to many thousand hours.

621.315.616 1335

New High-Softening Dielectric Materials—W. Mikucki. (*Brit. Commun. Electronics*, vol. 7, pp. 40–43; January, 1960.) Characteristics and electrical properties of new polymer materials with softening point above 100°C are tabulated.

MATHEMATICS

517.534:538.566 1336

On a Modification of Watson's Lemma—F. Oberhettinger. (*J. Res. Nat. Bur. Stand.*, vol. 63B, pp. 15–17; July–September, 1959.) "The method of steepest descents is extended to the case when a saddle point and a pole of arbitrary order are involved. An application to a problem in diffraction theory is demonstrated."

MEASUREMENTS AND TEST GEAR

621.317.3:621.391.822 1337

I.R.E. Standards on Methods of Measuring Noise in Linear Two-Ports, 1959—(PROC. IRE, vol. 48, pp. 60–68; January, 1960.) Standard 59 I.R.E. 20. S1.

621.317.33:537.312.8 1338

Sensitive Method for Measurement of Magnetoresistance Effect with Direct Currents and with Microwaves—D. E. Clark and J. G. Assenheim. (*Brit. J. Appl. Phys.*, vol. 11, pp. 35–38; January, 1960.) Measurements made using direct current and frequencies of 1.1, 1.5 and 9.2 kmc in fields up to 6270 oersteds are described. In general form the results agree with the theory of Donovan (2913 of 1954).

621.317.331:538.541 1339

Eddy-Current Method for Measuring the Resistivity of Metals—C. P. Bean, R. W. DeBlois and L. B. Nesbitt. (*J. Appl. Phys.*, vol. 30, pp. 1976–1980; December, 1959.) The resistivity is calculated from the rate of decay of flux from a bar situated in an external magnetic field that has been rapidly reduced to zero.

621.317.335.029.6 1340

Measurement of Dielectric Constants by the High-Order-Mode Interferometer—J. I. Caicoya. (*Brit. Commun. Electronics*, vol. 7, pp. 32–34; January, 1960.) An application of microwave equipment described earlier (3495 of 1956). The angle of refraction (Snell's refraction law) is determined for a uniform plane wave obliquely incident upon a dielectric sheet. 42 references.

621.317.343:621.372.83 1341

Measurement of the Impedance Matrix of Reciprocal Two-Port Junctions—C. Montebello. (*Note Recensioni Notiz.*, vol. 8, pp. 48–55; January/February, 1959.) A graphical method is proposed; measurements are made at one port only.

621.317.444:537.53 1342

Measurement of Ion Beam Currents using a Hall Effect Magnetometer—W. S. Whitlock and C. Hilsum. (*Nature*, vol. 185, p. 302; January 30, 1960.) A technique is described for measuring currents without interrupting the beam. Hall voltages are developed in an InSb crystal placed in the air gap of a mumetal ring through which the beam is passed. Two methods of applying the technique are given; the lowest beam current detected was about 10 μa.

621.317.444:550.380.8:629.136.3 1343

A Rocket-Borne Magnetometer—K. Burrows. (*J. Brit. IRE*, vol. 19, pp. 769–776; December, 1959.) The requirements of a rocket-borne magnetometer are outlined and the principles of measurement using a proton precession magnetometer are explained. The design, construction and testing of a practical instrument are described.

621.317.7 1344

A Programmed Test Set—D. W. Bradfield, A. M. East, and H. F. Rourke. (*Electronic Engrg.*, vol. 31, pp. 714–721; December, 1959.) Using uniselectors, complex electronic equipment can be checked more quickly and accurately than by manual methods.

621.317.733 1345

Wagner-Earth and other Null-Instrument Capacity Neutralizing Circuits—H. H. Wolff. (*Rev. Sci. Instr.*, vol. 30, pp. 1116–1122; December, 1959.) An exact theoretical treatment is given and its practical application to ac bridges discussed.

621.317.74:621.373.42.029.4 1346

Low-Distortion Sine-Wave Generator—A. R. Bailey. (*Electronic Tech.*, vol. 37, pp. 64–67; February, 1960.) Details are given of an RC oscillator operating in the range 10 cps–100 kc with distortion <0.02 per cent, designed for investigating the characteristics of sharply tuned rejector circuits.

621.317.742:621.372.86 1347

Microwave Reflectometer Techniques—G. F. Engen and R. W. Beatty. (TRANS. IRE ON MICROWAVE THEORY AND TECHNIQUES, vol. MTT-7, pp. 351–355; July, 1959.) Abstract, PROC. IRE, vol. 47, p. 1796; October, 1959.)

621.317.742:621.372.86 1348

Magnified and Squared V.S.W.R. Responses for Microwave Reflection-Coefficient Measurements—R. W. Beatty. (TRANS. IRE ON MICROWAVE THEORY AND TECHNIQUES, vol. MTT-7, pp. 346–350; July, 1959. Abstract, PROC. IRE, vol. 47, p. 1796; October, 1959.)

621.317.755 1349

Probability Density Measurement with an Electrode Mounted in the Face of a Cathode-Ray Tube—H. Lien. (*Rev. Sci. Instr.*, vol. 30, pp. 1100–1102; December, 1959.) "A small electrode mounted inside the face of a cathode-ray tube gives a 'window' comparable to its own dimensions when the bias voltages are set so that secondary electron emission current dominates. Under these conditions the device can be used for measurement of probability densities of random signals."

621.317.755 1350

Transient Storage Oscilloscope—A. E. Cawkwell and R. Reeves. (*Electronic Tech.*, vol. 37, pp. 50–59; February, 1960.) Details are given of a commercial oscilloscope incorporating a storage tube Type E702A. Normal oscilloscope facilities are also available.

621.317.789.029.64 1351

A Wide-Band High-Power Microwave Calorimeter—T. Jaeger and M. V. Schneider. (*Arch. elekt. Übertragung*, vol. 13, pp. 21–25; January, 1959.) A constant-flow method is used with the flow system entirely outside the main rectangular waveguide, so preventing electrical breakdown. The dissipative structure is coupled to the main guide by a wire grid in the guide wall. Power is measured by a substitution method, the total error being less than 2 per cent.

621.317.79:621.395.625.3.001.41 1352

A Versatile Clock System for Setting-Up and Testing Magnetic Drums—J. S. Arnold and D. L. Hood. (*A.T.E.J.*, vol. 15, pp. 2–14; January, 1959.) A transistor counter circuit and its application are described.

621.317.794 1353

Simplified Logarithmic Radiation Meter Using Noise—C. E. Cohn. (*Rev. Sci. Instr.*, vol. 30, pp. 1097–1099; December, 1959.) "A logarithmic radiation meter has been developed which uses an a.c.-coupled logarithmic voltmeter to measure the random noise from a photomultiplier detector. A range of four decades has been obtained."

621.317.794 1354

A Coaxial Film Bolometer for the Measurement of Power in the U.H.F. Band—I. A. Harris. (*Proc. IEE*, Part B, vol. 107, pp. 67–72; January, 1960.) The bolometer element is a thin cylindrical film forming the center conductor of a coaxial line; the outer conductor has an axial section in the form of a tractrix tapering until it meets the center conductor. A wide-band bolometer for measuring powers of 2–200 mw from 200 mc to 4 kmc with an accuracy within 1 per cent is described; designs for 2 watts up to 3 kmc and 0.1 mw up to 20 kmc are feasible.

OTHER APPLICATIONS OF RADIO AND ELECTRONICS

538.569.4:535.33:621.375.9 1355

Radio-Frequency Spectroscopy using Three-Level Maser Action—K. Shimoda. (*J. Phys. Soc. Japan*, vol. 14, pp. 954–959; July, 1959.)

621.3.087.4:678.5:537.533 1356

Thermoplastic Recording—W. E. Glenn. (*J. Appl. Phys.*, vol. 30, pp. 1870–1873; December, 1959.) Information is written by an electron beam on a film coated with low-melting-point thermoplastic. The pattern of charge is converted to a deformation pattern by heating the material.

621.362+621.56 1357

The Thermoelectric Figure of Merit and its Relation to Thermoelectric Generators—R. P. Chasmar and R. Stratton. (*J. Electronics Control*, vol. 7, pp. 52–72; July, 1959.) The figure of merit of a semiconductor of given carrier mobility and lattice thermal conductivity is evaluated numerically and presented graphically for various scattering indices. High-temperature limitations are considered and the results discussed in connection with various sulphides, selenides and tellurides.

621.362+621.56 1358

The Figure of Merit of a Thermoelectric Generator—R. Stratton. (*J. Electronics Control*, vol. 7, pp. 73–76; July, 1959.) Optimum conditions for a generator with n- and p-type semiconducting branches with different physical parameters are simply related to the optimum conditions for the figure of merit of a single substance.

621.362+621.56 1359

Effect of Heat Transfer on the Characteristics of Semiconductor Thermopiles for Refrigerators and Heat Pumps—G. Vikhorev and V. Naer. (*Fiz. Tverdogo Tela*, vol. 1, pp. 903–907; June, 1959.)

621.362 1360

Thermoelectricity—C. Celent. (*Electronic Ind.*, vol. 18, pp. 66–78; July, 1959.) A review of progress made in the development of thermoelectric and thermionic heat converters by manufacturers in U. S. A. Properties of a large number of materials are given in tabular form.

621.362:537.227 1361

Ferroelectrics Generate Power—(*Electronics*, vol. 32, pp. 88, 90; December 18, 1959.) The ferroelectric generator converts thermal to electrical energy by means of a ferroelectric capacitor. High output voltages may be obtained, and stages may be cascaded. One application is the generation of an ac voltage in a spinning satellite.

621.362:621.387 1362

Characteristics of a Plasma Thermocouple—Pidd, Grover, Salmi, Roehling, and Erickson. (*See* 1456.)

621.362:621.387 1363

Space-Charge Neutralization by Fission Fragments in the Direct-Conversion Plasma Diode—F. E. Jablonski, C. B. Leffert, R. Silver, R. F. Hill, and D. H. Loughridge. (*J. Appl. Phys.*, vol. 30, pp. 2017–2018; December, 1959.)

621.365.55:674 1364

Radio-Frequency Heating in Wood Gluing—J. Pound. (*Beama Jour.*, vol. 66, pp. 148–151; November, 1959.)

621.365.55:678.5 1365

Radio-Frequency Heating in the Plastics Industry—C. E. Tibbs. (*Beama Jour.*, vol. 66, pp. 144–147; November, 1959.) The use of pre-heating ovens and applications of dielectric welding of thermoplastic materials are described.

621.374.32:612.816 1366

Pulse-Height Analyser for Neuro-physiological Applications—R. M. Littauer and C. Walcott. (*Rev. Sci. Instr.*, vol. 30, pp. 1102–1106; December, 1959.) A five-channel instrument which allows the activity of one or more nerve fibres to be followed.

621.384.8:621.382.2 1367

Performance of Germanium and Silicon Surface-Barrier Diodes as Alpha Particle Spectrometers.—J. W. Mayer. (*J. Appl. Phys.*, vol. 30, pp. 1937–1944; December, 1959.)

621.385.833:061.3 1368

Summarized Proceedings of a Conference on Electron Microscopy—Exeter, July 1959—J. A. Chapman and M. J. Whelan. (*Brit. J. Appl. Phys.*, vol. 11, pp. 22–32; January, 1960.)

621.387.424 1369

Self-Quenching Geiger Counters containing Mixtures of Permanent Gases—A. J. L. Collinson, I. C. Demetsopoullos, J. A. Dennis, and J. M. Zarzycki. (*Nature*, vol. 185, p. 369; February 6, 1960.) An investigation of counters containing mixtures of argon with small quantities of xenon, oxygen and nitrogen to total pressures of 700 mm Hg. General conclusions are reached on the role of various components of the mixture in the production of the Geiger plateau.

621.398:551.508.77:621.396.96 1370

The Use of a Radar Beacon for Telemetering Precipitation Data—D. R. Soltow and R. D. Tarble. (*J. Geophys. Res.*, vol. 64, pp. 1863–1866; November, 1959.) Description of a radar interrogating system for obtaining a PPI display of tipping-bucket rain-gauge data from remote stations.

PROPAGATION OF WAVES

621.391.812.62 1371

Note on Amplitude Fluctuations of Distant Fields—F. du Castel. (*Ann. Télécommun.*, vol. 14, pp. 91–92; March/April, 1959.) Amplitude fluctuations over three 430 mc trans-horizon radio links in West Africa have been analyzed. Results show an amplitude distribution frequently different from that given by a Rayleigh-type law.

621.391.812.621 1372

Partial Reflections in the Atmosphere and Long-Distance Propagation: Part 3—F. du Castel, A. Spizzichino, P. Misme, and J. Voge. (*Ann. Télécommun.*, vol. 14, pp. 33–40; January/February, 1959.) The reflected field is considered to have two components, one specular and the other diffuse, the characteristics of each component obeying different laws. Parts 1 and 2: 1006 of March.

621.391.812.624 1373

A Note on Scatter Propagation—E. D. Denman. (Proc. IRE, vol. 48, pp. 112–113; January, 1960.) Scattering from a periodic dielectric perturbation is theoretically greatly enhanced if a certain wavelength ratio exists between the periodic disturbance and the EM energy. Experimental evidence is presented to support the theory.

621.391.812.624/.63:621.396.2 1374

Radio Transmission by Ionospheric and Tropospheric Scatter—(*See* 1392.)

621.391.812.8:681.142 1375

Computers aid Propagation Studies—(*Electronics*, vol. 32, pp. 50, 52; December 25, 1959.) General description of the application of computer techniques at the National Bureau of Standards particularly in the prediction of propagation conditions and the preparation of ionospheric and tropospheric contour maps.

RECEPTION

621.376.23 1367

Transient Cross-Modulation in the Detection of Asymmetric-Sideband Signals—T. Murakami and R. W. Sonnenfeldt. (*RCA Rev.*, vol. 20, pp. 455–472; September, 1959.) Envelope and synchronous or product detection methods are compared with reference to transient cross-modulation. Under correct phasing conditions synchronous detection may be made distortionless for asymmetric-sideband signals.

621.391.812.3:621.3:621.3.087.6 1377

Fading-Rate Recorder for Propagation Re-

search—J. W. Koch, W. B. Harding and R. J. Jansen. (*Electronics*, vol. 32, pp. 78–80; December 18, 1959.) An instrument which provides strip-chart recordings simultaneously of signal strength and average fading rates from almost zero to 300 cps is described.

621.391.821:621.317.34 1378
The Measurement of Atmospheric Radio Noise by an Aural Comparison Method in the Range 15–500 kc/s—J. Harwood and B. N. Harden. (*Proc. IEE*, Part B, vol. 107, pp. 53–59; January, 1960.) "Atmospheric noise received on a vertical aerial is compared with a locally generated keyed signal to estimate the level at which the signal is 95% intelligible. This method was used in earlier high-frequency equipment and has been adapted for the range 15–500 kc/s. The apparatus and its method of operation are described. Results obtained at a number of sites are discussed in relation to more objective measurements. In particular, deduced noise powers are compared with existing world-wide predictions, revealing some differences."

621.391.822:621.317.794 1379
Ultra-Low Noise Measurements using a Horn Reflector Antenna and a Travelling-Wave Maser—R. W. DeGrasse, D. C. Hogg, E. A. Ohm, and H. E. D. Scovil. (*J. Appl. Phys.*, vol. 30, p. 2013; December, 1959.) Sky noise has been measured at 5.65 km cps with an antenna having a 2 degree beam width pointed at an angle of θ to the zenith. When $\theta=0$, the sky temperature was found to be 2.5°K and it varied according to sec θ up to $\theta=80$ degrees.

621.391.822.001.2 1380
Methods of Calculation for Noise Phenomena—K. Lunze. (*NachrTech.*, vol. 8, pp. 530–537; December, 1958.) The calculation of the noise-power spectrum, and representation by equivalent noise quadripoles are considered.

621.391.827:621.396.41 1381
Crosstalk due to Finite Limiting of Frequency-Multiplexed Signals—C. R. Cahn. (PROC. IRE, vol. 48, pp. 53–59; January, 1960.) The case of a narrow gap in random noise is analyzed to determine the output signal/crosstalk ratio in the selected channel as a function of clipping level. An optimum level is determined and applied to frequency-multiplex binary data transmission.

621.396.621.52:621.385.633 1382
Application of a Backward-Wave Amplifier to Microwave Autodyne Reception—J. K. Pulfer. (TRANS. IRE ON MICROWAVE THEORY AND TECHNIQUES, vol. MTT-7, pp. 356–359; July, 1959. Abstract, PROC. IRE, vol. 47, p. 1796; October, 1959.)

621.396.66:621.316.726.078.3 1383
Spectrum-Selection Automatic Frequency Control of Ultra-Short-Pulse Signalling Systems—H. Kihn and R. J. Klensch. (*RCA Rev.*, vol. 20, pp. 499–517; September, 1959.) A system is described which maintains a constant frequency difference between a carrier frequency modulated by ultra-short pulses of 10 mμsec duration and a local electrically tuned oscillator.

621.396.662.078 1384
DOPLOC uses Phase-Locked Filter—F. M. Gardner. (*Electronic Ind.*, vol. 18, pp. 96–99; October, 1959.) Description of an automatic Doppler-frequency tuning system which improves the signal-to-noise ratio of a received satellite signal by 43 db.

621.396.666:621.391.812.3 1385
Diversity Reception of Two Correlated Signals—F. du Castel and J. Derennes. (*Ann. Télécommun.*, vol. 14, pp. 41–42; January/February, 1959.) The influence of Gaussian signal distribution on diversity gain is examined and compared with the gain for a Rayleigh distribution [see 1862 of 1956 (Staras)].

621.396.666:621.396.4 1386
Multiple Diversity with Non-independent Fading—J. N. Pierce and S. Stein. (PROC. IRE, vol. 48, pp. 89–104; January, 1960.) The performance of an optimum (maximal-ratio) combiner is analyzed for an arbitrary number of diversity branches. Possible correlation between components of various signals is considered. Simplifications can be made in special cases and examples of application to digital communication problems are given.

STATIONS AND COMMUNICATION SYSTEMS

621.376.2 1387
The Computation of Single-Sideband Peak Power—W. K. Squires and E. Bedrosian. (PROC. IRE, vol. 48, pp. 123–124; January, 1960.) The average-to-peak SSB power ratio is derived for a continuous range of modulating signals from sinusoidal to square waveforms.

621.391 1388
Instantaneous Complex Frequency. Definition and Measurement—P. Braffort and R. Castagne. (*Compt. rend.*, vol. 249, pp. 854–856; August 17, 1959.) The concept of instantaneous complex frequency may be used for a signal modulated in any way. Principles of measurement for certain cases are described.

621.391 1389
Instantaneous Spectrum and Analysis of a Signal Simultaneously in Frequency and Time—P. Deman. (*Ann. Télécommun.*, vol. 14, pp. 21–32; January/February, 1959.) An analytical method is proposed for studying under interference conditions, a signal which is considered to be a succession of elementary signals represented in two dimensions by frequency and time. Practical aspects of the system are discussed.

621.396:621.395 1390
Voice Radio Systems for High-Noise Paths—J. A. Greefkes and F. de Jager. (*Electronics*, vol. 32, pp. 53–57; December 11, 1959.) By transmitting speech amplitude and speech frequency on different channels a communications link can be operated under poorer noise conditions than with either SSB or FM systems. Operation is possible with a signal-to-noise ratio of 4 db.

621.396.2:621.376.55 1391
Phase-Shift Keying in Fading Channels—H. B. Voelcker. (*Proc. IEE*, Part B, vol. 107, pp. 31–38; January, 1960.) A theoretical analysis of the effect of fading and noise on phase-shift keying, a modulation technique with reduced bandwidth and superior to frequency-shift keying at relatively low signal-to-noise ratios.

621.396.2:621.391.812.624/.63 1392
Radio Transmission by Ionospheric and Tropospheric Scatter—(PROC. IRE, vol. 48, pp. 4–44; January, 1960.) A report of the U. S. Joint Technical Advisory Committee prepared as a supplement to *Radio Spectrum Conservation, 1952* (see 2446 of 1953). The report is in two sections covering ionospheric scatter transmission and long-range tropospheric transmission. Each section summarizes present knowledge concerning propagation theories, experimental data, design practice, fields of application, and factors affecting frequency allocation.

621.396.4 1393
Recent Communications Systems Developments—M. M. Perugini. (*Electronics*, vol. 32, pp. 72–75; December 18, 1959.) A summary of five papers presented at the Fall Meeting of the AIEE, Chicago, 1959, covering recent developments in microwave, telegraph and telephone systems.

621.396.43:551.507.362.2 1394
Satellite Test Open to All—(*Electronics*, vol. 32, pp. 44–45; December 18, 1959.) A note on "Project Echo" for which a 100-foot-diameter metallized balloon is to be launched into a 1000-mile-altitude earth orbit during spring 1960, to act as a passive communications reflector.

621.396.65:621.372.55 1395
Automatic Control of Distortion in Wide-Band-Frequency-Modulated Microwave Links—J. Tolman. (*Electronic Engrg.*, vol. 31, pp. 722–725; December, 1959.) An experimental automatic equalizer for correcting group delay slope is described and results are given for a 600-channel circuit. The basic equations are developed, and curves are given for intermodulation group delay distortion.

621.396.65:621.391.8 1396
Investigation of the Telegraphic Quality in Transhorizon Radio Beams—F. du Castel and J. P. Magnen. (*Ann. Télécommun.*, vol. 14, pp. 93–103; March/April, 1959.) An evaluation of the telegraphic quality obtained when some of the telephony channels of a multiplex system are used for telegraphy. Results show that, assuming good-quality telephonic reception, CCITT quality for telegraphy can only be ensured by the use of a diversity reception system. With a quadruple-diversity system the number of hours of interrupted service on the telegraphy link would be less than those for the telephone link. The influence of rapid fading on the telegraphic signal is discussed.

621.396.65:621.397 1397
Radio Link Equipment in the 3800–4200-Mc/s Band—J. Dascotte. (*Onde elect.*, vol. 39, pp. 769–784; October, 1959.) Terminal equipment is described for an 819-line television link having two double-sideband channels.

SUBSIDIARY APPARATUS

621–526:621.375.4 1398
A Transistor Quadrature Suppressor for A.C. Servo Systems—I. C. Hutcheon and D. N. Harrison. (*Proc. IEE*, Part B, vol. 107, pp. 73–82; January, 1960.) The spurious quadrature component in the error signal of an ac servo-system is cancelled by a self-balancing circuit including thermistors.

621.3.087.9:621.383 1399
Photoelectronic Chart Reader of Recorded Ink Line—H. Yuhara, K. Nakajima, S. Koizumi, Y. Nakamura, and Y. Endow. (*J. Radio Res. Labs., Japan*, vol. 6, pp. 705–719; October, 1959.) Design and construction details are given of an equipment which samples the level of a recorded line once every second and produces an integrated analog output voltage.

621.314.1:621.382.3 1400
Transistor Regulated D.C./D.C. Converter—A. Tailleur. (*Onde élect.*, vol. 39, pp. 795–801; October, 1959.) Regulation is controlled by a blocking oscillator whose frequency varies as a function of the error voltage. Details are given of a 100-watt regulator.

621.314.63 1401
On the Non-isothermal Diffusion Theory of Rectifiers—T. Numata. (*J. Phys. Soc. Japan*, vol. 14, pp. 902–913; July, 1959.) A general theory is developed from formal conduction

theory; the rectification equation obtained depends upon temperature distributions in a barrier. Values of the dielectric constant of barrier materials in Cu_2O and Se rectifiers, determined by analysis of experimental results using the new theory, tend to approach those of the bulk materials.

621.316.721.078.3:538.569.4 1402

Stabilization of a Direct Current or a Magnetic Field by Paramagnetic Resonance—R. Reimann. (*Compt. rend.*, vol. 249, pp. 517–519; July 27, 1959.) Description of a system for current stabilization based on electron resonance in a sample of paramagnetic material such as diphenyl-picryl-hydrazyl.

621.316.721.078.3:621.318.381 1403

A Simple Current Stabilizer for Electromagnets—M. H. N. Potok. (*Electronic Engrg.*, vol. 31, pp. 745–746; December, 1959.) The design of a stabilizing circuit operating with an amplidyne generator is described which gives 10 amperes at 100 volts with stability within 5 parts in 10^5.

621.316.721.078.3:621.318.381 1404

A Transistorized Current Stabilizer for an Electromagnet—J. C. S. Richards. (*Electronic Engrg.*, vol. 32, pp. 22–23; January, 1960.) An auxiliary electromechanical control system permits an output of up to 4 amperes at 200 volts with current stability within ±2 parts in 10^4 over 10 hours.

TELEVISION AND PHOTOTELEGRAPHY

621.397:621.391.822 1405

The Interference caused by Noise Fluctuations of Irregular Spectral Distribution—E. Sennhenn. (*Elektron. Rundschau*, vol. 13, pp. 9–12; January, 1959.) Subjective tests were made to assess the dependence of the interference effect at different noise frequencies on picture brightness and content. The subjective noise sensitivity for the noise spectra of conventional scanning tubes is evaluated.

621.397.132 1406

From Monochrome to Colour Television—Santos and Dintzner. (*Onde élect.*, vol. 39, pp. 823–826; October, 1959.) General description of a closed-circuit simultaneous color-television system with a compact camera unit weighing 5 kg.

621.397.132:621.395.625.3 1407

Magnetic Recording of Colour Television—J. Roizen. (*Electronics*, vol. 33, pp. 76–79; January 1, 1960.) Description of a system used commercially giving details of the method of maintaining the timing accuracy within 2 mμsec for faithful color reproduction. Special attention is given to the servosystem which controls the tape transport.

621.397.132:621.397.331.222 1408

Production of Fine Patterns by Evaporation—S. Gray and P. K. Weimer. (*RCA Rev.*, vol. 20, pp. 413–425; September, 1959.) Methods for measuring the scattering of material at a wire masking grill are described. Various techniques for reducing the scattering have been applied in the construction of an experimental target for a tricolor camera tube.

621.397.331.22 1409

The Testing and Operation of $4\frac{1}{2}$-in. Image-Orthicon Tubes—D. C. Brothers. (*J. Brit. IRE*, vol. 19, pp. 777–805; December, 1959.) The basic principles of the image orthicon are described. The parameters affecting picture quality are examined in detail. Suggestions are made for the setting up and operation of this tube to obtain the best compromise between the requirements of the different parameters.

621.397.331.24:621.318.4 1410

Bilateral Linearity Regulator—R. Suhrmann and M. Meyer. (*Frequenz*, vol. 13, pp. 11–15; January, 1959.) In the device described, a coil wound on a magnetically soft ferrite tube with ceramic permanent-magnet core is used to correct deflection linearity at the beginning and end of the line.

621.397.6.001.4 1411

The International Development of the Test-Line Technique in Television—H. E. Fröling. (*Frequenz*, vol. 13, pp. 1–10, 147–155, and 175–183; January, May, and June, 1959.) Details are given of the test systems adopted by various international broadcasting organizations. See also 679 of February (Springer). 48 references

621.397.6.001.41:621.391.837 1412

The Test Pattern of the Swiss Television Network—H. Probst. (*Tech. Mitt. PTT*, vol. 37, pp. 41–44; February 1, 1959.) Technical details are given and the interpretation of the pattern is discussed.

621.397.743 1413

Frequency Translators for the Television Service—H. Hesselbach. (*Frequenz*, vol. 13, pp. 21–25; January, 1959.) German and U.S. equipment is described with reference to standardized requirements.

TUBES AND THERMIONICS

621.382 1414

A CdS Analogue Diode and Triode—W. Ruppel and R. W. Smith. (*RCA Rev.*, vol. 20, pp. 702–714; December, 1959.) A comparison is made between space-charge-limited current flow through a vacuum and through a solid insulator. Diode and triode operation analogous to the corresponding vacuum devices is obtained by applying ohmic and blocking contacts to the insulator. Practical operation of both diode and triode is described, using a CdS single crystal 10μ thick.

621.382:621.318.57 1415

A Review of Semiconductor Switching Devices and Associated Design Requirements—A. W. Matz. (*A.T.E.J.*, vol. 15, pp. 61–82; January, 1959.) 131 references.

621.382.2 1416

Modulation of Diffusion Length as a New Principle of Operation of Semiconductor Devices—V. I. Stafeev. (*Fiz. Tverdogo Tela*, vol. 1, pp. 841–847; June, 1959.) In diodes with a large d/L ratio, where d is the diode thickness and L the effective diffusion length, the forward current is highly sensitive to changes in L. Specially shaped diodes have been prepared which show a) high magnetic-field sensitivity, b) a negative-resistance region in the I/V characteristic, and c) high photosensitivity (up to 100 amp/lumen). An avalanche mechanism is described accounting for these characteristics and for phenomena occurring in Ge diodes with Au and Fe impurities. An amplifier operating on this basis with a supplementary p-n junction in the diode wafer is proposed.

621.382.2 1417

On the Problem of the Volt-Ampere Characteristic of a Diode at Ultra-High Injection Levels—V. I. Stafeev. (*Fiz. Tverdogo Tela*, vol. 1, pp. 848–850; June, 1959.) Development of an expression derived earlier (*Zh. tekh. Fiz.*, vol. 28, pp. 1631–1641; August, 1958) giving the total voltage drop across a p-n junction diode.

621.382.2 1418

Impact Ionization in an n-p Junction—G. V. Gordeev. (*Fiz. Tverdogo Tela*, vol. 1, pp. 851–860; June, 1959.) Investigation of the current multiplication resulting from impact ionization. The boundaries of the transition region and the potential drop in the n and p regions are examined and an expression is derived for the multiplication factor in the case of an abrupt junction.

621.382.2 1419

Effect of Internal Heating on the Breakdown Characteristics of Silicon p-n Junctions—B. Senitzky and P. D. Radin. (*J. Appl. Phys.*, vol. 30, pp. 1945–1950; December, 1959.) Simple avalanche theory explains the onset of the breakdown, but experiment shows that the shape of the V/I curve in this region is determined mainly by the internal heating.

621.382.2 1420

Heat-Treatment Centres and Bulk Currents in Silicon p-n Junctions—D. J. Sandiford. (*J. Appl. Phys.*, vol. 30, pp. 1981–1986; December, 1959.) Lifetime measurements on alloy p-n junctions made from heat-treated n-type Si show that space-charge generation is the important mechanism for diodes with the shortest lifetimes, while surface leakage is predominant for diodes in the μsec range.

621.382.2 1421

The Optimum Noise Performance of Tunnel-Diode Amplifiers—K. K. N. Chang. (Proc. IRE, vol. 48, pp. 107–108; January, 1960.) It is shown analytically that for a given I/V characteristic a minimum value exists for the product of the excess noise factor and a gain factor.

621.382.2/.3:621.391.822 1422

Investigation of the Temperature Variation of Noise in Diode and Transistor Structures—C. A. Lee and G. Kaminsky. (*J. Appl. Phys.*, vol. 30, pp. 1849-1855; December, 1959.) "Measurements of the white noise of transistors (principally diffused-base structures) and diodes have been made at temperatures ranging from ~77°K to 300°K for a range of about two decades in injection level, and from 10 kc/s to 10 Mc/s. Comparisons of the noise measurements with calculated levels are presented. The germanium transistors show a progressively increasing deviation from the theory as the temperature is decreased, and most of the silicon transistors exhibited excess white noise at room temperature and below."

621.382.3:539.12.04 1423

Selecting Transistors for Radiation Environments—J. R. Bilinski and R. Merrill. (*Electronics*, vol. 32, pp. 38–40; December 25, 1959.) Minority-carrier lifetime and hence the grounded-emitter current gain are degraded upon irradiation. Equations are derived for this effect and nomographs are drawn for Ge and Si transistors.

621.382.3:621.376.32 1424

Reactance Transistor—Fujimura and Mii. (*See* 1171.)

621.382.3:621.391.822.3 1425

Shot Noise in Transistors—A. van der Ziel. (Proc. IRE, vol. 48, pp. 114–115; January, 1960.) The modified shot-noise theory for Si transistors is discussed to take account of trapping effects in the emitter space-charge region. See 2413 of 1959 (Schneider and Strutt).

621.382.3–71:621.362 1426

Transistor Operation Aided by Thermoelectric Refrigeration—H. J. Goldsmid and R. A. Hilbourne. (*Brit. Commun. Electronics*, vol. 7, pp. 26–30; January, 1960.) Thermoelectric cooling applied to Ge and Si transistors is considered. The range of temperature over which a Ge HF transistor may be operated can be extended upwards by at least 50°C.

621.382.333 1427

Equivalent Circuit and Amplifier Characteristics of Junction Transistors—W. Moortgat-Pick. (*Arch. elekt. Übertragung*, vol. 13, pp. 33–48 and 82–89; January and February, 1959.) The equivalent circuit given by Giacoletto (1193 of 1955) is modified to enable transistor characteristics to be calculated accurately under small-signal conditions for emitter currents up to about 5 ma and frequencies up to 10 mc.

621.382.333 1428

Variation of Input Conductance of a Grounded-Base Junction Transistors—S. Deb and J. K. Sen. (*Electronic Engrg.*, vol. 31, pp. 753–755; December, 1959.) Methods are suggested for maintaining the variation linear over a wide range of currents. Methods of reducing thermal drift are also considered. Results are given.

621.382.333 1429

Transistor Avalanche Voltage—L. van Biljon. (*Electronic Tech.*, vol. 37, pp. 72–76; February, 1960.) An expression giving the collector avalanche voltage in an alloyed junction transistor as a function of base resistance is developed from simple considerations of transistor currents.

621.382.333 1430

Frequency Dependence of the Noise and the Current Amplification Factor of Silicon Transistors—E. R. Chenette. (PROC. IRE, vol. 48, pp. 111–112; January, 1960.) Experimental evidence is presented concerning the discrepancies between theoretical and experimental behavior of Ge transistors at low temperature and of Si transistors.

621.382.333.001.4 1431

Life-Testing of Germanium Power Transistors—B. J. Cooper and R. E. Ireland. (*Brit. Commun. Electronics*, vol. 7, pp. 14–19; January, 1960.) Heat-cycling and full-load tests have been made on a limited number of *p-n-p* junction transistors. Results indicate that unreliable transistors may be detected during an artificial aging process following manufacture.

621.383.27 1432

An Image Intensifier with Transmitted Secondary-Electron Multiplication—W. L. Wilcock, D. L. Emberson, and B. Weekley. (*Nature*, vol. 185, pp. 370–371; February 6, 1960.) An experimental image intensifier is described which produces a total electron multiplication of 3.5×10^3 and a ratio of light output to input of 8×10^4 when the incident light is of the same mean wavelength as the phosphor emission.

621.383.4 1433

Sintered Cadmium Sulphide Photoconductive Cells—C. P. Hadley and E. Fischer. (*RCA Rev.*, vol. 20, pp. 635–647; December, 1959.) Results of a long development program are given. Topics discussed include fabrication techniques, properties of the host materials, activation impurities, electrodes and packaging.

621.383.4:535.215–15 1434

Infrared Photoconductive Detectors using Impurity-Activated Germanium-Silicon Alloys—G. A. Morton, M. L. Schultz, and W. E. Harty. (*RCA Rev.*, vol. 20, pp. 599–634; December, 1959.)

621.383.4:535.371.07 1435

The Role of Space-Charge Currents in Light Amplifiers—A. Rose and R. H. Bube. (*RCA Rev.*, vol. 20, pp. 648–657; December, 1959.) Basic relations determining the performance of the photoconductive-electroluminescent light amplifier are given, and the importance of space-charge current flow in the photoconductor is emphasized. The performance capabilities of present photoconductors are analyzed.

621.383.4:535.371.07 1436

Properties of a Single-Element Light Amplifier using Sintered Cadmium Selenide Photoconductive Material—F. H. Nicoll. (*RCA Rev.*, vol. 20, pp. 658–669; December, 1959.) Moderate gains with high output luminance are possible with speeds in a range suitable for moving pictures. Operating characteristics are given.

621.383.4:535.371.07 1437

Solid-State Image Intensifier under Dynamic Operation—C. P. Hadley and R. W. Christensen. (*RCA Rev.*, vol. 20, pp. 670–681; December, 1959.) Simple theoretical analysis of dynamic operation is confirmed experimentally. Suggestions for improving performance are made.

621.383.4:535.371.07 1438

Optical-Feedback-Type Storage Light Intensifiers—H. O. Hook. (*RCA Rev.*, vol. 20, pp. 744–752; December, 1959.) Three designs of storage intensifier were tested. Constructional details are given and performances compared.

621.385.032.212:537.533 1439

New Cold Cathode using Magnesium Oxide—T. Imai, Y. Mizushima, and Y. Igarashi. (*J. Phys. Soc. Japan*, vol. 14, pp. 979–980; July, 1959.) Report of an effect observed using light pulses to initiate cathode emission. For a constant flash-time the integrated exposure time of the cathode before emission commenced was found to be independent of the time between flashes.

621.385.032.213.13 1440

Doping Influences on Activator Diffusion Oxide-Coated Cathode Nickel—H. Mizuno. (*J. Phys. Soc. Japan*, vol. 14, pp. 1295–1301; October, 1959.) Doping by Mn, Fe or Si decreases the diffusion coefficient of Mg, and doping by Mg increases the diffusion coefficient of Mn.

621.385.032.531 1441

Determination of Lead-Wire Inductances in Miniature Tubes—W. A. Harris and R. N. Peterson. (*RCA Rev.*, vol. 20, pp. 485–598; September, 1959.) Measurements of internal inductances and resonance frequencies in miniature valves operating in the UHF band are described.

621.385.3 1442

Influence of Grid Current on the Oscillations of a Triode—L. Sideriades and J. Bitoun. (*Onde élect.*, vol. 39, pp. 810–815; October, 1959.) The effect of grid current may be represented by simple resistance and capacitance elements in conjunction with the grid circuit inductance.

621.385.3 1443

The Behaviour of Triodes in the Transit-Time Region under Large-Signal Conditions—G. Heinzmann. (*Arch. elekt. Übertragung*, vol. 13, pp. 13–20; January, 1959.) The effect of increasing drive on input impedance, gain and efficiency is investigated theoretically, and the results are compared with those obtained from measurements by other authors.

621.385.3:621.317.723 1444

Logarithmic Characteristic of Triode Electrometer Circuits—S. K. Chao. (*Rev. Sci. Instr.*, vol. 30, pp. 1087–1092; December, 1959.) An electrometer tube Type CK5889 can be used as a logarithmic circuit element in the grid current range $10^{-14}-10^{-6}$ ampere. Its application in an ionization-chamber survey instrument is described.

621.385.6:621.391.822 1445

Noise in Electron Beams and in Four-Terminal Networks—M. T. Vlaardingerbroek. (*Philips Res. Rep.*, vol. 14, pp. 327–336; August, 1959.) Calculation of the minimum noise figure of electron-beam amplifiers, obtained by varying the properties of the drift space, is shown to be analogous to the calculation of the minimum noise figure of a quadripole by varying the signal-source impedance.

621.385.6:621.391.822 1446

Noise Propagation on Uniformly Accelerated Multi-velocity Electron Beams—W. M. Mueller and M. R. Currie. (*J. Appl. Phys.*, vol. 30, pp. 1876–1880; December, 1959.) Low values of beam noisiness can be obtained by reducing the slope of the potential profile. Adjustment of this parameter provides a practical possibility of attaining low noise figures in slow space-charge wave amplifiers as the frequency is increased.

621.385.623.5.072.6 1447

Frequency Stabilization of a Reflex-Klystron Oscillator—F. Bruin and D. Van Ladesteyn. (*Physica*, vol. 25, pp. 1–8; January, 1959.) See 93 of 1954 (Bruin).

621.385.624.2 1448

An Experimental Investigation of a Two-Cavity Klystron Operating under Large-Signal Conditions—I. M. Stephenson. (*Proc. IEE*, Part B, vol. 107, pp. 60–66; January, 1960.) Measurements on a klystron with a variable drift space confirm the space-charge effects predicted by recent theory, both for small and large signals. The effect of a large signal is to reduce the optimum drift length. The change-over from small- to large-signal conditions is governed by the ratio of signal frequency to plasma frequency, as well as by the modulating RF voltage.

621.385.63:621.375.9:621.372.44 1449

Fast-Wave Couplers for Longitudinal-Beam Parametric Amplifiers—A. Ashkin, W. H. Louisell, and C. F. Quate. (*J. Electronics Control*, vol. 7, pp. 1–32; July, 1959.) Theoretical considerations lead to new methods of treating the problem and two special cases are considered. A design procedure is given for a system consisting of a Kompfner dip helix (3206 of 1950) preceded and followed by a velocity jump.

621.385.632 1450

Medium-Power L- and S-Band Electrostatically Focused Travelling-Wave Tubes—D. J. Blattner, F. E. Vaccaro, C. L. Cuccia, and W. C. Johnson. (*RCA Rev.*, vol. 20, pp. 426–441; September, 1959.) Description of the "Estiatron" which has a bifilar helix as both RF circuit and electrostatic focusing structure and can be used with either a parallel-flow or convergent-flow electron gun of conventional design.

621.385.632.3 1451

General Aspects of Beating-Wave Amplification—W. G. Dow and J. E. Rowe. (PROC. IRE, vol. 48, p. 115; January, 1960.) A method is suggested for large amplification under high-power conditions by coupling between electron beams with differing phase velocities.

621.385.633.1.029.65 1452

Type-O Carcinotrons Operating at 2 mm Wavelength—Yeou-Ta. (*Onde elect.*, vol. 39, pp. 789–794; October, 1959.) Results obtained with an experimental valve using permanent-magnet focusing are given. See also 4011 *1* of 1958 (Laborderie *et al.*).

621.385.64 **1453**

Tuning and the Equivalent Circuit of Multiresonator Magnetrons—T. S. Chen. (*J. Electronics Control*, vol. 7, pp. 33–51; July, 1959.) An equivalent circuit is synthesized from the input-admittance function determined from the properties of the waveguide used to calculate wide-band tuning characteristics, which agree with measurements for waveguide tuning systems with and without iris coupling.

621.385.832.032.269.1 **1454**

Cathode-Ray-Tube Triode Gun with Beam Former Electrode—W. F. Niklas. (PROC. IRE, vol. 1, pp. 120–121; January, 1960.) A substantial reduction in astigmatic aberrations has been obtained.

621.387:621.316.722.078.3 **1455**

The Characteristics and Applications of Corona Stabilizer Tubes—E. Cohen and R. O. Jenkins. (*Electronic Engrg.*, vol. 32, pp. 11–15; January, 1960.) These hydrogen-filled tubes are suitable for voltage stabilization in the range 350–4000 volts. Minimum stabilized current is a few microamperes. Maximum continuous current varies from 400 μa, for the low-voltage tubes, to 1 ma for the highest-voltage tubes. At 200 μa the noise output varies from 6 mv rms for the smallest tubes to 165 mv for the largest.

621.387:621.362 **1456**

Characteristics of a Plasma Thermocouple—R. W. Pidd, G. M. Grover, E. W. Salmi, D. J. Roehling, and G. F. Erickson. (*J. Appl. Phys.*, vol. 30, pp. 1861–1865; December, 1959.) The operation of a caesium thermocouple is described for a range of hot-junction temperatures from 1600° to 2600°K and for caesium pressures from 10^{-5} to 2 mm Hg. The EMF's observed are between 1 and 4.5 volts and the largest short-circuit current density obtained is 62 amp/cm^2.

621.387:621.362 **1457**

Space-Charge Neutralization by Fission Fragments in the Direct-Conversion Plasma Diode—F. E. Jablonski, C. B. Leffert, R. Silver, R. F. Hill, and D. H. Loughridge. (*J. Appl. Phys.*, vol. 30, pp. 2017–2018; December, 1959.)

621.38:621.391.822 **1458**

Noise in Electron Devices [Book Review]—L. D. Smullin and H. A. Haus (Eds.). Mass. Inst. Tech. Press, Cambridge, Mass.; John Wiley and Sons, Inc., New York, N. Y. and Chapman and Hall, London, Eng. 413 pp.; 1959. (*Proc. Phys. Soc.*, vol. 74, p. 800; December 1, 1959.)

MISCELLANEOUS

621.3.39+681.142 **1459**

Radio Electronics—A. M. Kugushev. (*Uspekhi Fiz. Nauk.*, vol. 67, pp. 663–703; April, 1959.) Survey of progress since the early work of Popov (1859–1906) reviewing developments in radio communication, television, radar, radio astronomy, solid-state devices, particle accelerators and computers. 130 references.

621.37/.38 **1460**

Latest Trends in Electron Devices—M. F. Wolff. (*Electronics*, vol. 32, pp. 31–33; December 25, 1959.) The developments outlined include improved storage and display devices, logic elements in the form of photoconductive-electroluminescent panels, various low-noise and solid-state amplifiers, and a concentric-electrode photomultiplier.

621.37/.39:061.3 **1461**

The Ninth Plenary Assembly of the C.C.I.R.—J. W. Herbstreit. (PROC. IRE, vol. 48, pp. 45–53; January, 1960.) A summary of the work of the fourteen study groups at the assembly in Los Angeles, Calif. April, 1959.

621.39(047.1) **1462**

Communication Engineering and Radiolocation—(*VDI Z.*, vol. 102, pp. 177–190; February 11, 1960.) Progress report covering recent developments with references mainly to German literature. The following sections are surveyed:

a) **Sound Broadcasting and Television**—E. Schwartz (pp. 177–182). 121 references.

b) **Telecommunications**—W. Althans (pp. 182–184).

c) **Electroacoustics**—H. Harz (pp. 184–186).

d) **High-Frequency Measurements**—H. Brunswig (pp. 186–188).

e) **Radar and Radio Navigation**—W. Stanner (pp. 188–190).

Translations of Russian Technical Literature

Listed below is information on Russian technical literature in electronics and allied fields which is available in the U. S. in the English language. Further inquiries should be directed to the sources listed. In addition, general information on translation programs in the U. S. may be obtained from the Office of Science Information Service, National Science Foundation, Washington 25, D. C., and from the Office of Technical Services, U. S. Department of Commerce, Washington 25, D. C.

PUBLICATION	FREQUENCY	DESCRIPTION	SPONSOR	ORDER FROM:
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Automation and Remote Control (Avtomatika i Telemekhanika)	Monthly	Complete journal	National Science Foundation—MIT	Instrument Society of America 313 Sixth Ave., Pittsburgh 22, Pa.
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Journal of Abstracts, Electrical Engineering (Reseratívnyy Zhurnal: Electronika)	Monthly	Abstracts of Russian and non-Russian literature		Office of Technical Services U. S. Dept. of Commerce Washington 25, D. C.
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Proceedings of the USSR Academy of Sciences: Applied Physics Section (Doklady Akademii Nauk SSSR: Otdel Prikladnoi Fiziki)	Bimonthly	Complete journal		Consultants Bureau, Inc. 227 W. 17 St., New York 22, N. Y.
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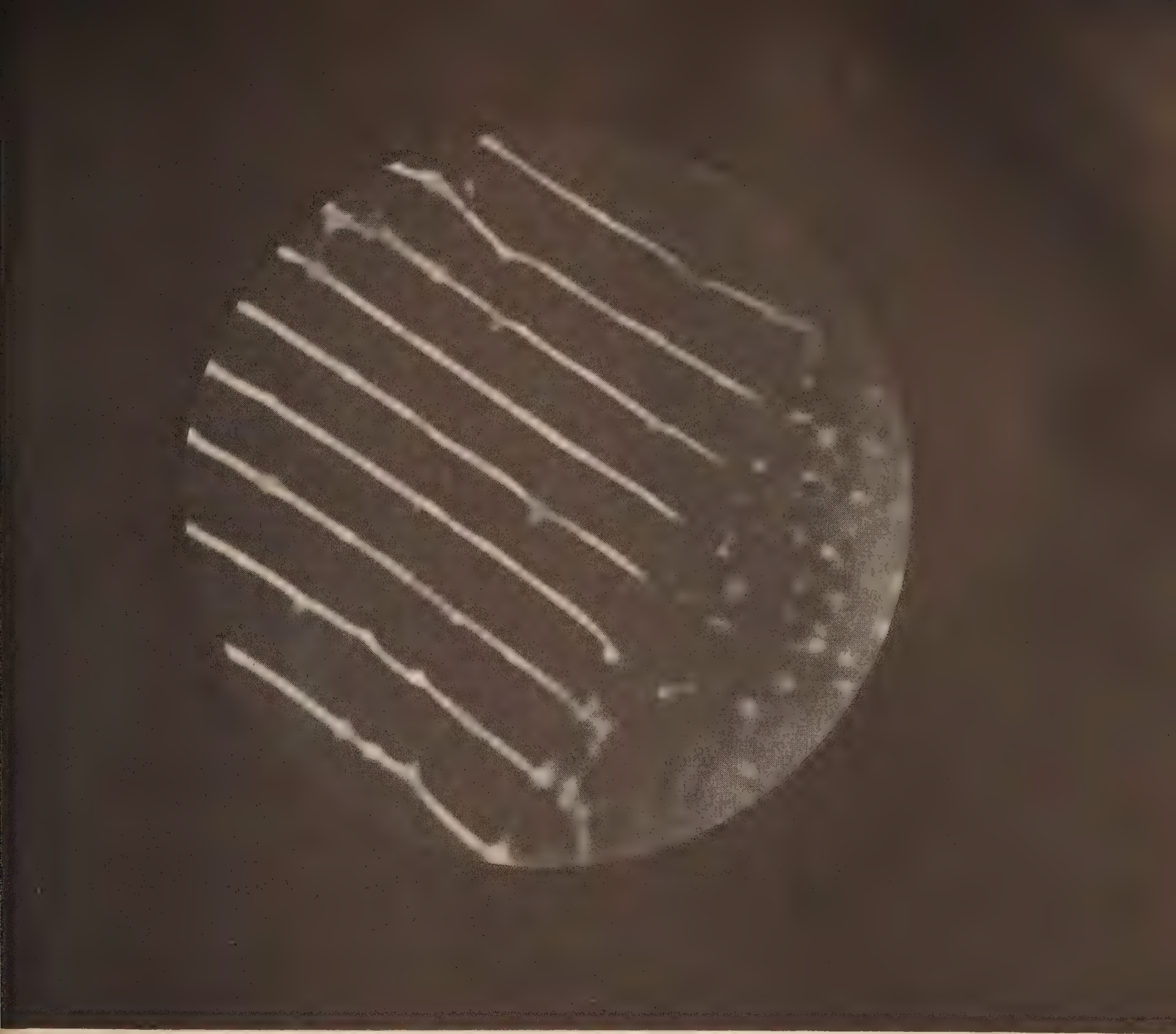

Bit densities are revealed by the electron mirror microscope through the behavior of electrons reflected by the magnetic fringe fields of recorded data.

Reflections from an Electron Mirror

e photograph is a representation of the
gnetic fringe fields above a small por-
n of a recording surface. Behind these
gnified tracks of recorded data is the
ry of a device now decades old in prin-
le, but which has only recently been
plied to the study of high-density mag-
ic information storage.

The electron mirror microscope was con-
ucted by IBM scientists as a laboratory
trument. Based on the excellent resolu-
capabilities of an electron beam, the
ctron mirror principle has its primary
plication in the observation of tiny mag-
ic fringe fields.

n the operation of an electron mirror
roscope, an electron beam is accelerated down a tube toward a specimen mounted on a conductive plate with a negative potential relative to the cathode. At the zero equipotential surface in the tube, the electrons traveling toward the specimen change their directions and are reflected in somewhat the same way light rays are reflected by a mirror. By controlling the potentials of the cathode and the conductive plate, the "mirror" can be placed at any height above the magnetic surface. When the mirror is set close enough to the surface to be in the fringe fields of recorded information, these fields distort the return paths of electrons in the beam. Passing the return beam through a magnetic lens results in a magnified representation on a phosphor viewing plate, capable of resolving bit densities far greater than those in use in present systems.

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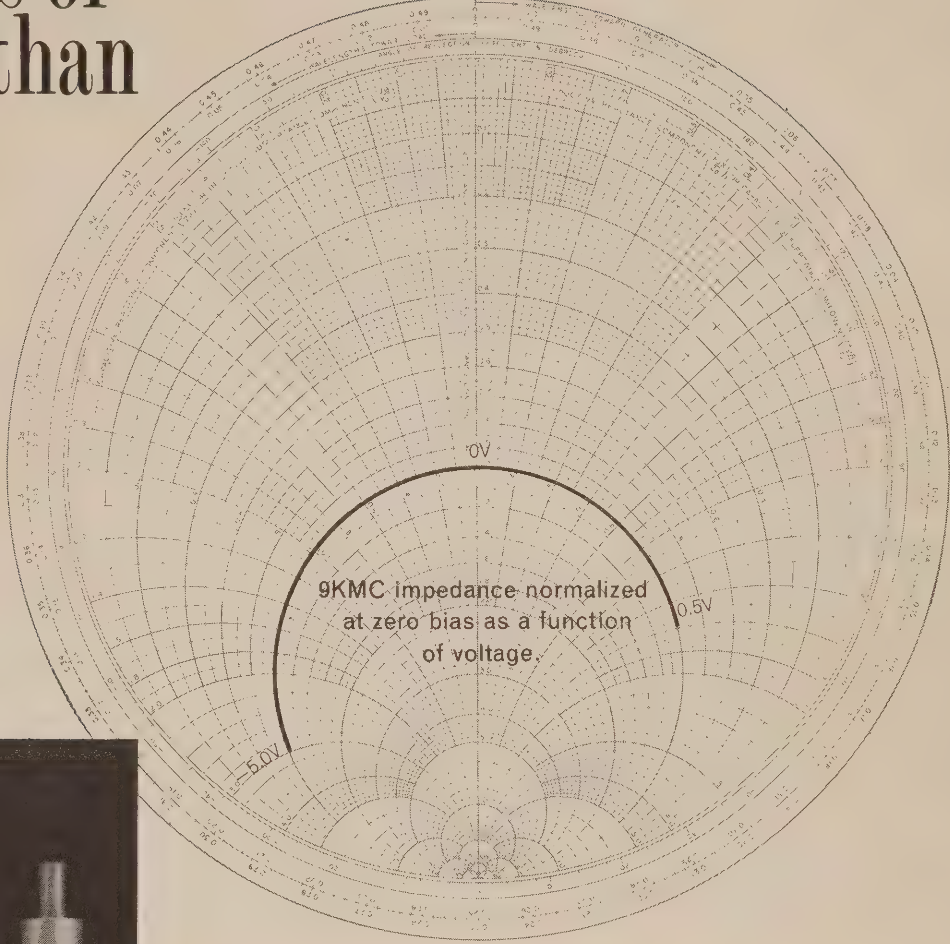

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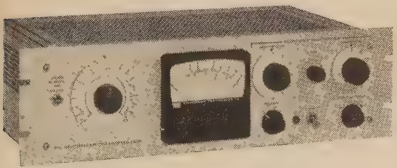

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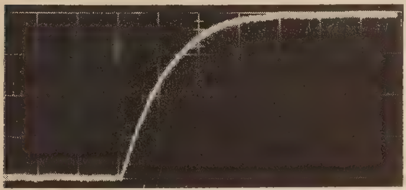

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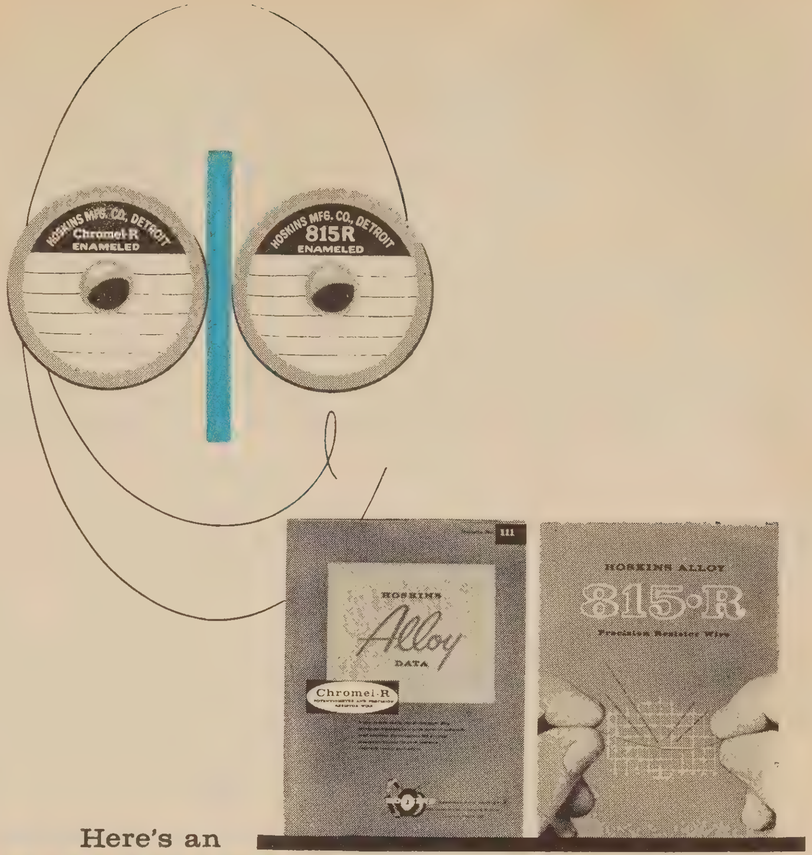

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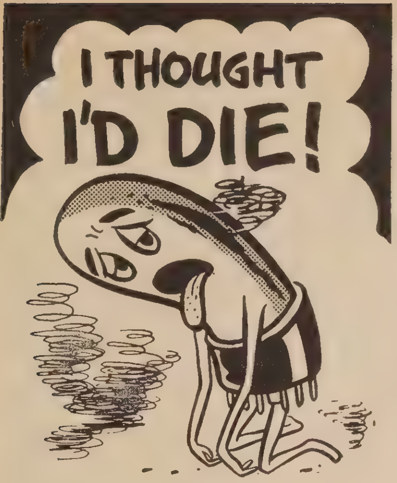
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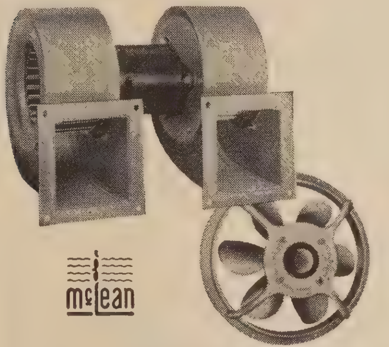

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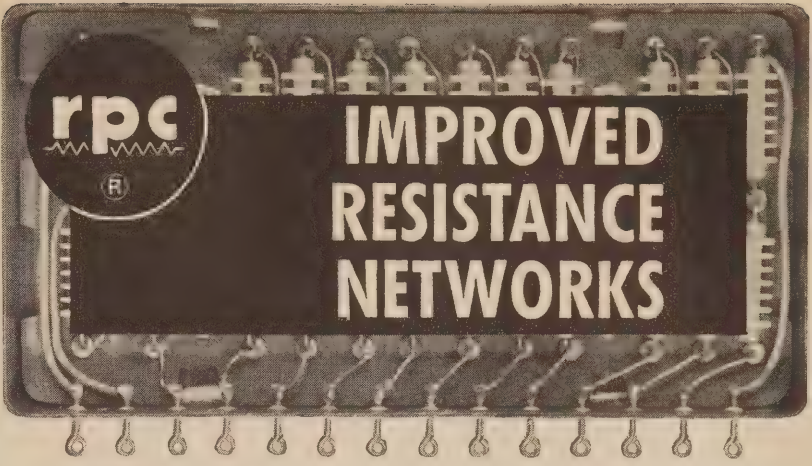

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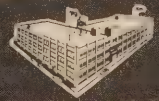

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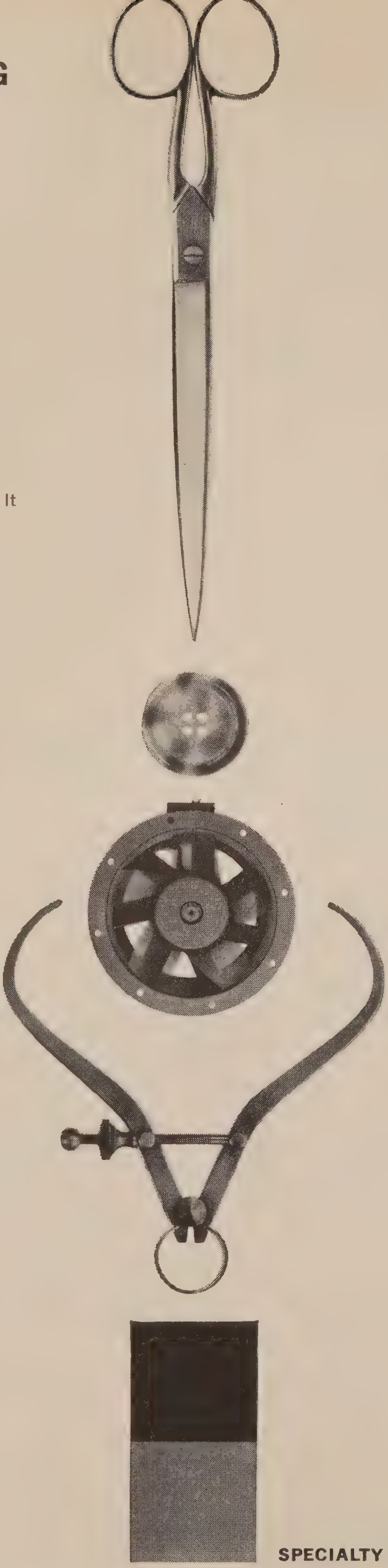

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(Continued on page 112A)

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Mr. H-S. Knowles, Chairman, Knowles Electronics, 9400 Belmont Ave., Franklin Park, Ill.

50 Transactions, *Vol. AU-1, No. 6; *Vol. AU-2, No. 1, 4; Vol. AU-3, No. 1, 3, 5; Vol. AU-4, No. 1, 5-6; Vol. AU-5, No. 1, 2, 3, 4, 5, 6; AU-6, No. 1, 2, 3, 4, 5, 6; AU-7, No. 1, 2, 3, 4, 5, 6.

Automatic Control

Annual fee: $2.

The theory and application of automatic control techniques including feedback control systems.

Mr. John E. Ward, Chairman, Servomechanisms Lab., MIT, Cambridge 39, Mass.

8 Transactions, PGAC-3-4-5-6, AC-4, No. 1; AC-5, No. 1.

Broadcast & Television Receivers

Annual fee: $2.

The design and manufacture of broadcast and television receivers and components and activities related thereto.

Mr. Robert R. Thalner, Chairman, Sylvania Home Electronics, Batavia, N.Y.

24 Transactions, *7, 8; BTR-1, No. 1-4; BTR-2, No. 1-2-3; BTR-3, No. 1-2; BTR-4, No. 2, 3-4; BTR-5, No. 1, 2, 3.

Broadcasting

Annual fee: $2.

Broadcast transmission systems engineering, including the design and utilization of broadcast equipment.

Mr. George E. Hagerty, chairman, Westinghouse, 122 E. 42nd St., New York 17, N.Y.

15 Transactions, No. 2, 4, 6, 7, 8, 9, 10, 11, 12, 13, 14; BC-6, No. 1.

Circuit Theory

Annual fee: $3.

Design and theory of operation of circuits for use in radio and electronic equipment.

Mr. Sidney Darlington, Chairman, Bell Tel. Labs., Murray Hill, N.J.

26 Transactions, CT-2, No. 4; CT-3, No. 2; CT-4, No. 3-4, CT-5, No. 1, 2, 3, 4, CT-6, No. 1, 2, 3; CT-7, No. 1.

Communications Systems

Annual fee: $2.

Radio and wire telephone, telegraph and facsimile in marine, aeronautical, radio-relay, coaxial cable and fixed station services.

Mr. J. E. Schlaijker, Chairman, IT&T, 67 Broad St., New York 4, N.Y.

16 Transactions, CS-2, No. 1; CS-5, No. 2, 3; CS-6, No. 1, 2; CS-7, No. 1, 2, 3, 4.

Component Parts

Annual fee: $3.

The characteristics, limitation, applications, development, performance and reliability of component parts

Mr. J. J. Drvostep, Chairman, Sperry Gyroscope Co., Great Neck, N.Y.

18 Transactions, Vol. CP-3, No. 2; CP-4, No. 1, 2, 3-4; CP-5, No. 1, 2, 3, 4; CP-6, No. 1, 2, 3, 4.

Education

Annual fee: $3.

To foster improved relations between the electronic and affiliated industries and schools, colleges, and universities.

Dr. John G. Truxal, Chairman, Dept. of EE, PIB, Brooklyn, N.Y.

9 Transactions. Vol. E-1, No. 3, 4; E-2, No. 1, 2, 3, 4; E-3, No. 1.

Electron Devices

Annual fee: $3.

Electron devices, including particularly electron tubes and solid state devices.

Dr. W. M. Webster, Chairman, RCA Labs., Princeton, N.J.

27 Transactions, *Vol. ED-1, No. 3-4; ED-3, No. 2-4; ED-4, No 2-3, 4; ED-5, No. 2, 3, 4; ED-6, No. 1, 3; ED-7, No. 1.

Electronic Computers

Annual fee: $4.

Design and operation of electronic computers.

Dr. A. A. Cohen, Chairman, Remington-Rand Univac, St. Paul 16, Minn.

31 Transactions, EC-6, No. 2, 3; EC-7, No. 1, 2, 3, 4; EC-8, No. 1, 2, 3.

Engineering Management

Annual fee: $3.

Engineering management and administration as applied to technical, industrial and educational activities in the field of electronics.

Dr. Henry M. O'Bryan, Sylvania Elec. Products, 730 3rd Ave., New York 17, N.Y.

17 Transactions, EM-3, No. 2, 3; EM-4, No. 1, 3, 4; EM-5, No. 1-4; EM-6, No. 1, 2, 3; EM-7, No. 1.

Engineering Writing and Speech

Annual fee: $2.

The promotion, study, development, and improvement of the techniques of preparation, organization, processing, editing, and delivery of any form of information in the electronic-engineering and related fields by and to individuals and groups by means of direct or derived methods of communication.

Mr. T. T. Patterson, Jr., Chairman, RCA Bldg. 13-2, Camden, N.J.

5 Transactions, Vol. EWS-1, No. 2; EWS-2, No. 1, 2, 3.

Human Factors in Electronics

Annual fee: $2.

Development and application of human factors and knowledge germane to the design of electronic equipment.

Mr. Curtis M. Jansky, Chairman, Royal McBee Corp., Port Chester, N.Y.

1 Transaction, HFE-1, No. 1.

THE INSTITUTE OF RADIO

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the group chairman, and publications to date.

* Indicates publications still available

Industrial Electronics

Annual fee: $3.

Electronics pertaining to control, treatment and measurement, specifically, in industrial processes.

Mr. J. E. Eiselein, Chairman, RCA Victor Dev., Camden, N.J.

11 Transactions, *PGIE 1, 3, 5, 6, 7, 8, 9, 10, 11.

Information Theory

Annual fee: $3.

Information theory and its application in radio circuitry and systems.

Dr. Peter Elias, Chairman, MIT, Cambridge 39, Mass.

19 Transactions, PGIT-4, IT-1, No. 2, 3; IT-2, No. 3; IT-3, No. 1, 2, 3, 4; IT-4, No. 1, 2, 3, 4; IT-5, No. 1, 2, 3, 4.

Instrumentation

Annual fee: $2.

Measurements and instrumentation utilizing electronic techniques.

Mr. C. W. Little, Jr., Chairman, C-Stellerator Assoc., Princeton, N.J.

16 Transactions, 4; Vol. 1-6, No. 2, 3, 4; Vol. 1-7, No. 1, 2; Vol. 1-8, No. 1, 2, 3.

Bio-Medical Electronics

Annual fee: $3.

The use of electronic theory and techniques in problems of medicine and biology.

Mr. W. E. Tolles, Chairman, Airborne Instruments Lab., Mineola, N.Y.

16 Transactions, 8, 9, 11, 12; ME-6, No. 1, 2, 3; ME-7, No. 1.

Microwave Theory and Techniques

Annual fee: $3.

Microwave theory, microwave circuitry and techniques, microwave measurements and the generation and amplification of microwaves

Dr. A. A. Oliner, Microwave Research Institute, 55 Johnson St., Brooklyn 1, N.Y.

28 Transactions, MTT-4, No. 3-4; MTT-5, No. 3, 4; MTT-6, No. 1, 2, 3, 4; MTT-7, No. 2, 3, 4; MTT-8, No. 1.

Military Electronics

Annual fee: $2.

The electronics sciences, systems, activities and services germane to the requirements of the military. Aids other Professional Groups in liaison with the military.

Mr. Henry Randall, Chairman, Office of Asst. Secy. Defense, Pentagon, Washington, D.C.

8 Transactions, MIL-1, No. 1; MIL-2, No. 1; MIL-3, No. 2, 3, 4; MIL-4, No. 1.

Nuclear Science

Annual fee: $3.

Application of electronic techniques and devices to the nuclear field.

Dr. A. B. Van Rennes, Chairman, United Research, Inc., Cambridge, Mass.

15 Transactions, NS-1, No. 1; NS-3, No. 2, 3; NS-4, No. 2; NS-5, No. 1, 2, 3, NS-6, No. 1, 2, 3, 4.

Production Techniques

Annual fee: $2.

New advances and materials applications for the improvement of production techniques, including automation techniques.

Mr. L. M. Ewing, Chairman, General Electric Co., Syracuse, N.Y.

6 Transactions, No. 2-3, 4, 5, 6.

Radio Frequency Techniques

Annual fee: $2.

Origin, effect, control and measurement of radio frequency interference.

Mr. J. P. McNaul, Chairman, Signal Corps, USA's RDL, Ft. Monmouth, N.J.

1 Transaction, RF-1, No. 1.

Reliability and Quality Control

Annual fee: $3.

Techniques of determining and controlling the quality of electronic parts and equipment during their manufacture.

Mr. P. K. McElroy, Chairman General Radio Co., West Concord, Mass.

16 Transactions, *3, 5-6, 10, 11, 12, 13, 14, 15, 16.

Space Electronics and Telemetry

Annual fee: $2.

The control of devices and the measurement and recording of data from a remote point by radio.

Mr. C. H. Hoeppner, Chairman, Radiation, Inc., Melbourne, Fla.

14 Transactions, TRC-1, No. 2-3; TRC-2, No. 1; TRC-3, No. 2, 3; TRC-4, No. 1; SET-5, No. 1, 2, 3, 4.

Ultrasonics Engineering

Annual fee: $2.

Ultrasonic measurements and communications, including underwater sound, ultrasonic delay lines, and various chemical and industrial ultrasonic devices.

Dr. Wilfred Roth, Chairman, Roth Lab., Hartford, Conn.

8 Transactions, PGUE, 5, 6, 7; UE-7, No. 1.

Vehicular Communications

Annual fee: $2.

Communications problems in the field of land and mobile radio services, such as public safety, public utilities, railroads, commercial and transportation, etc.

Mr. A. A. MacDonald, Chairman, Motorola, Inc., 4545 W. Augusta Blvd., Chicago 51, Ill.

13 Transactions, 5, 8, 9, 10, 11, 12, 13.

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Ace's standard sine-cosine line includes sizes from 3/4″ to 3″, driving resistances from 1K to 1 megohm, in comparable conformities from 0.5%, peak to peak. So if you think you have a special requirement — talk to us! Chances are it's an Ace *standard* sine-cosine pot!

This 3/4″ sine-cosine ACEPOT® features conformity of 1.0%, peak to peak, in a resistance range of 1K to 30K. Other driving resistance ranges and conformities available.

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Acepot® Acetrim* Aceset® Aceohm® *Reg. Appl. for

Industrial Engineering Notes

(Continued from page 108A)

and devices (including but not limited to antenna structures, pedestals, drives, launchers, trailers, platforms, pallets, elevators, gimbals, and handling equipment); computing and associated information processing devices (except airborne); scientific industrial and laboratory instruments; x-ray tubes and apparatus; electrotherapeutic and electromedical instruments and apparatus; telephone and telegraph equipment (including but not limited to radio telephone and radio telegraph devices of the kind generally manufactured for the use of public utility communications systems); and electronic control devices other than electronic missile guidance and missile control devices (including but not limited to signals, alarms and automatic industrial controls)."

Section Meetings

Alamogordo-Holloman

"Modern or Third Channel Stereo," Paul Klipsch. 2/8/60.

Albuquerque-Los Alamos

"Engineering Problems Relative to Tektronix 519 Design and Applications," C. Moulton, Tektronix, Inc. 2/29/60.

Anchorage

"The Preservation of the History and Artifacts of Early Alaskan Communications," Col. C. A. Thorpe, HQ, Alaskan Command. 1/4/60.

"Polar Blackouts," Dr. G. C. Reid, Geophysical Institute. 2/1/60.

"Technical discussion of Generation of the Television Signal and Video Tape Recording," J. M. Walden, Northern Television, Inc. 3/7/60.

Bay of Quinte

"Surface Wave Transmission Lines," A. P. Treu, Northern Electric Co., Ltd. 2/17/60.

Benelux

"Solar Radio Noise and Its Relation to Some Geophysical Phenomena," A. H. de Voogt; F. R. Neubauer; A. D. Fokker; L. D. Feiter—all of Netherlands PTT. 3/5/60.

Binghamton

"The Next Hundred Years," Dr. C. C. Furnas, University of Buffalo. 2/24/60.

Central Florida

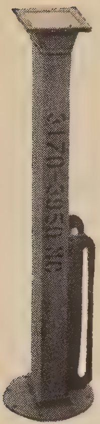
"Environmental Testing," Dr. Brittain, Electronic Communication, Inc. 2/18/60.

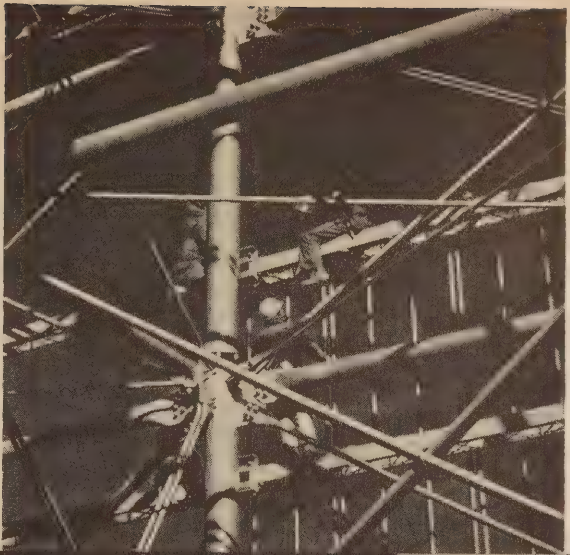
Cincinnati

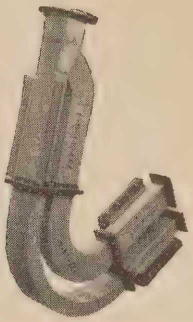
"Some Color Slide and Color Television Experiments Using the Land Technique," Dr. W. L. Hughes, Iowa State University; "Piercing the Unknown" and "The Information Machine," J. Marquandt, IBM Corp.; "A Transistorized Preamplifier for Magnetic Pickups," Prof. A. B. Bereskin, University of Cincinnati. 1/18/60.

"Function of the IRE," Dr. R. L. McFarlan, President of the IRE; "Behind the Scenes in Air Traffic Control," B. F. Green, Air Force Cambridge Research Center. 3/1/60.

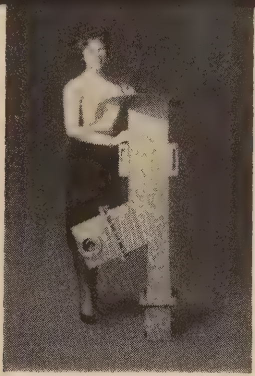
(Continued on page 116A)







Beyond the Black Boxes...



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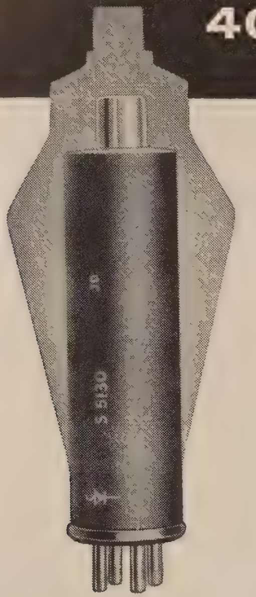
TARZIAN
Silicon Rectifiers do more than replace these 40 tube types



5AU4	5AW4	5AZ4	5T4
5U4	5V4	5Y4	5W4
5Y3	5Z4	6X4	6063
6202	80	82	83
83V	5Z3	0Z4	5X4
6AX5	6X5	5AU4	5931
6087	6106	5R4	6AU4
6AX4	6BL4	6U4	6W4
12AX4	17AX4	25W4	816
836	3B28	866	866A

Some common vacuum rectifier types that Tarzian silicon rectifiers replace

THEY ALSO PROVIDE:

1. Higher current ratings
2. Inherently rugged construction
3. Instant operation; no warmup
4. Greater electrical stability
5. Improved voltage regulation

Tarzian tube replacement silicon rectifiers combine the advantages of solid state rectification and direct interchangeability with over 95% of all popular rectifier tube types. Although the silicon units are generally smaller than the tubes they replace, their dc current ratings are substantially higher, as much as three times as great in some ratings.

If you have a rectifier application requiring high efficiency, long life, rugged construction, or wide temperature range, Tarzian tube replacement silicon rectifiers may solve your problem. They are available in nine standard models. Special designs and modifications can be worked out on request.

For specifications and prices of tube replacement silicon rectifiers, contact your Sarkes Tarzian sales representative or distributor, or write to Section 4615F, Sarkes Tarzian, Inc., Semiconductor Division, Bloomington, Indiana.

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Better than 1μv Audio-band Noise in a Stereo Preamp?

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Stereo console

Only an engineer can fully appreciate the performance characteristics and quality of construction offered in Marantz equipment. As an example, only the Marantz model 7 *Stereo Console can give you these features:*

- Unique very-low-noise input circuit.
- Equivalent total noise input, 20-20000 cps: 0.8 μv, typical; 1 μv max. (total noise, 60db below 1 mv input where Zgen = 2000 ohms max.)
- Noise-selected film resistors in sensitive plate and cathode circuits.
- Mu-metal shielded, hum-bucking power transformer.
- Hum inaudible through thermal noise, even with RIAA phono curve.
- Well filtered DC for heaters.
- Carefully designed grounding system for minimum hum.
- Tubes and main assembly on heavy, fully shock-mounted turret terminal board.
- Laced cables.
- Incremental tone controls accurately resettable in each channel. Each step switches individual feedback network, "Flat" position cuts out reactive components.
- Hermetically sealed, ganged volume control with better than 2 db tracking at any setting to —65db. Attenuation range, 90db.
- Tape recording and monitoring facilities.
- I.M. distortion, 10 V equiv. pk. RMS, 60-7000 cps 4:1 ratio: less than 0.15% (Proportionately less at normal output levels)
- Gain: Phono (RIAA); 64½db @ 1000 cps. Stepup transformers not needed. High Level: 22½db.
- 15 Amp power switch. 6 AC line outlets for 1700 watts associated equipment.
- Heavy brushed aluminum panel, finely machined knobs, anodized pale gold color. Rack mounting to order in clear anodized aluminum finish at slightly higher cost.
- Every unit completely tested and adjusted to meet specs. Test card included.

The model 8 Stereo Amplifier is a perfect match in standard of performance and construction. While many amplifiers *measure* quite well on sine wave test, this has little relation to their behavior toward the transient signals encountered in musical material. The exceptionally clean overload characteristics, instantaneous recovery, and unconditional stability of the model 8, shows up where it counts—on the loudspeaker! It easily outperforms and outdrives high fidelity amplifiers presently available.

- More than 30 watts per channel (over 40 W with selected tubes)
- Silicon power supply includes Sprague 17D (telephone quality) Electrolytics for reliability.
- Metered adjustments for both static and dynamic balance.
- Open circuit noise 90db below rated power.
- Cool-running, conservative operation.
- Harmonic distortion at full rated power—less than 0.1% @ 1000 cps, 0.5% @ 20 cps, 1% @ 20 kc. Proportionately less at lower output.

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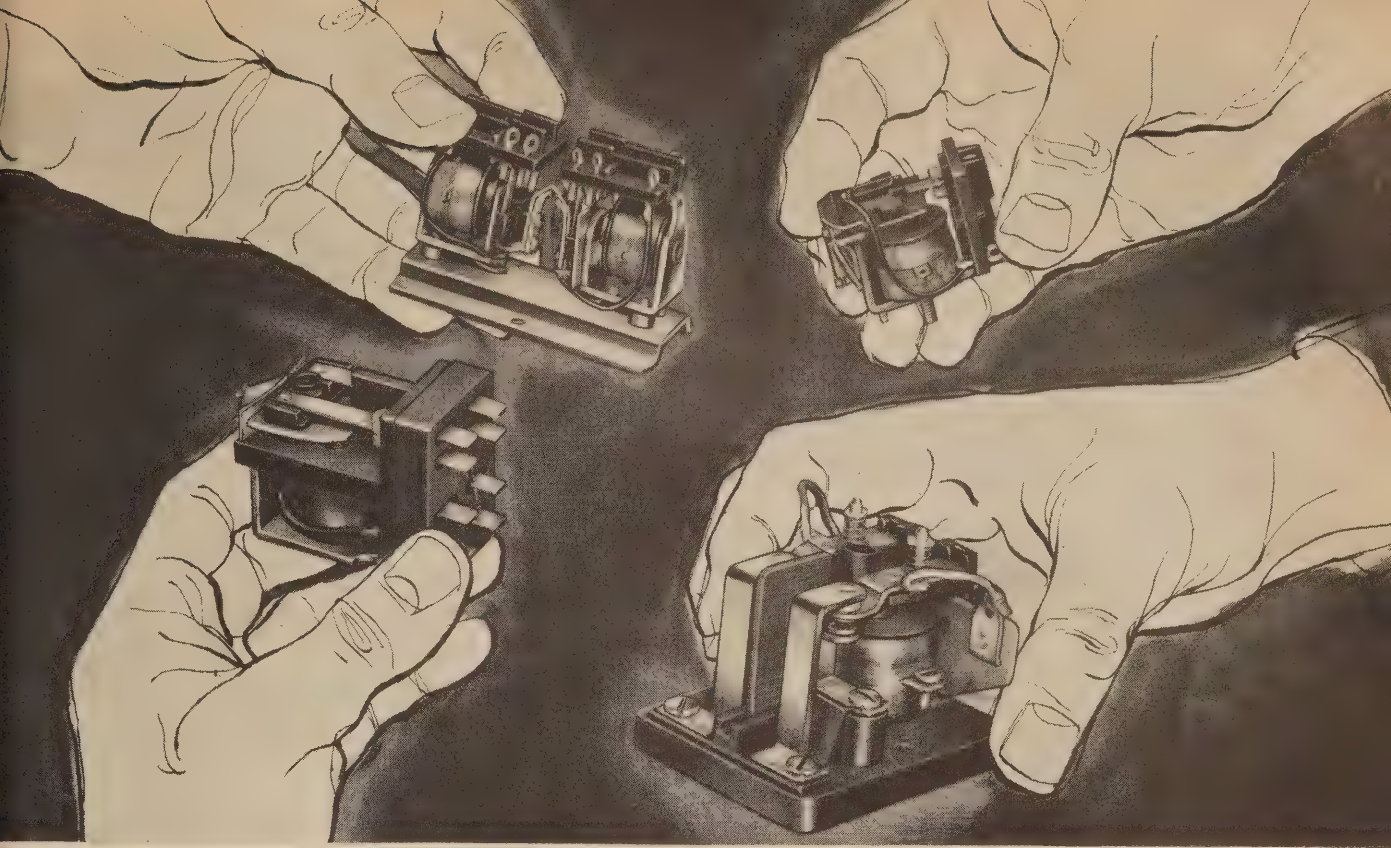

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More than 40 different standard P&B relays in 450 different coil voltages and contact arrangements are available from the leading Electronic Part Distributors in your area. For special applications, call your nearest P&B sales engineer.

PR Series

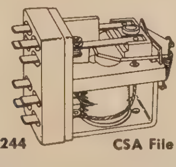
Type	Contact Arrangement*	Type	Contact Arrangement*
PR1AY	SPST-NO	PR5AY	SPDT
PR3AY	SPDT-NO-DM	PR7AY	DPST-NO
		PR11AY	DPDT

These relays are available in any of the following operating voltages: 6, 12, 24, 115, 230 volts 50/60 cycles AC.

Contacts are rated at: 25 amps, 115/230 V. AC 1 phase. 1 hp for 115/230 volt AC motors 1 phase.

*Read: NO normally open, NC normally closed, DB double break, DM double make.

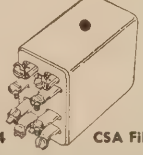
U/L File E22575 **CSA File 15734**



AB Series

U/L File E29244 **CSA File 15734**

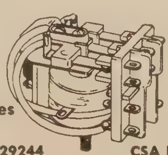
For appliance and general purpose operations requiring long life and quiet operation. Quick connect terminals. Screw terminal adapters also furnished with each relay. Contact arrangement: DPDT. Rated at 10 amps, 115 V., 5 amps, 230 AC non-inductive by U/L and CSA.



ABC Series

U/L File E29244 **CSA File 15734**

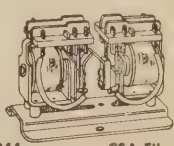
Medium duty power relay in dust cover. For small motors, industrial controls and similar applications. Contact arrangement: DPDT. Rated at 10 amps, 115 V., 5 amps, 230 AC non-inductive by U/L and CSA.



KA Series

U/L File E29244 **CSA File 15734**

Small, low cost, general purpose relay for handling automation work, small motors, solenoids, other relays. Contact arrangements: SPDT, DPDT and 3PDT. Rated at 5 amps, at 115 V., AC non-inductive by U/L and CSA.



KB Series

U/L File E29244 **CSA File 15734**

Compact latch relay ideal for memory work and overload applications. Operates on momentary impulse to either coil. Contact arrangements: 4PDT and 6PDT. Rated at 5 amps at 115 V., AC non-inductive by U/L and CSA.

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DIVISION OF AMERICAN MACHINE & FOUNDRY COMPANY, PRINCETON, INDIANA

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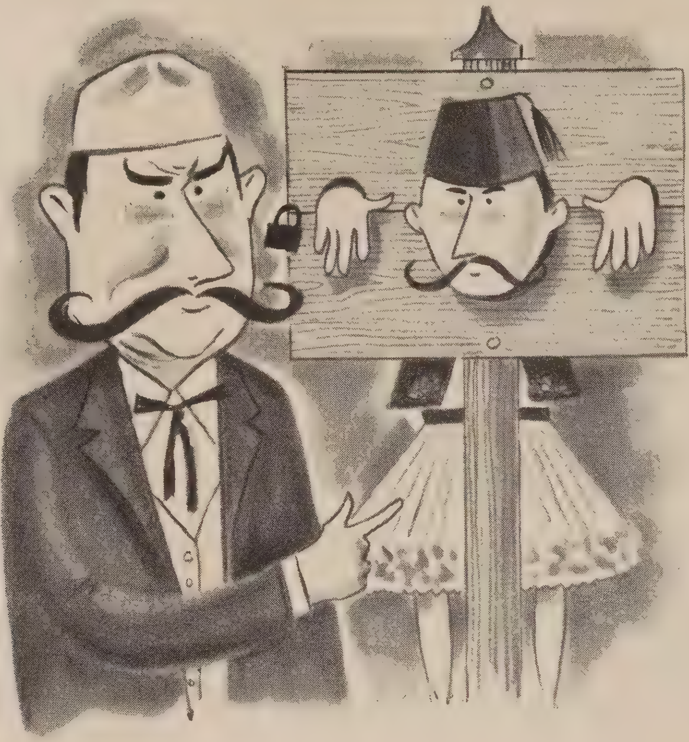
DEEP THOUGHTS FROM DEEP DOMES / NO. 4 OF A SERIES

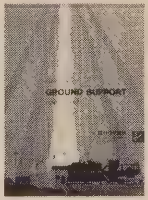


Zoster on Education

"Education is the process of moving from cocksure ignorance to thoughtful uncertainty," said Dr. Herpes Sophocles Zoster (1823-1887), famed Athenian teacher, inventor of the Patent Disciplinator for Hardnosed Pupils, summing up some of our modern no-go missile experience years ahead of his time. We know one missileman who has handworked this sentiment in needlepoint to hang by his blockhouse window, where he can see it as he triggers the Mark VII-C Rocket Destructor.

But dawn is imminent. Emerging from its brown study of thoughtful uncertainty, HOOVER ELECTRONICS COMPANY has *Taken Steps,* and a whole family of accurate, reliable, versatile, flexible (even repeatable) Electronic Ground Support Equipment has been born: test sets, data translators, tracking equipment, instrumentation-control vans, and others. Steps *toward* Carefree Certainty, to say the least.

Well, to get to the point quickly, space in this magazine being priced beyond rubies, we at HOOVER ELECTRONICS have produced a handsome folder about the EGSE hinted at coyly above. We wouldn't be reluctant to send a copy, if you'd just put your name and address on a letterhead. Today, eh?



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Field Liaison Engineers
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Section Meetings

(Continued from page 112A)

Cleveland

"Silicon Controlled Rectifiers," Panel discussion. Moderator, J. Flick, Jack & Heintz, Inc. Panalists: E. E. Von Zastrow, G.E. Co.; R. McKenna, Texas Instruments, Inc.; Eric Jackson, Transitron, Inc. 2/11/60.

Columbus

"The Technical Society in Your Life and Vice-Versa," H. A. Bolz, Ohio State University. Presentation of Student Awards. 3/7/60.

Dallas

"Advanced Energy Conversion Principles," R. L. Petriz, Texas Instruments, Inc. 2/18/60.

"Engineering Management," P. E. Haggerty, Texas Instruments, Inc. 2/23/60.

"Radio Engineering in Controlled Fusion Research," W. W. Salisbury, Varo Mfg. Co.; 2/25/60.

"Masers," F. R. Arams, Cutler-Hammer, Inc. 3/3/60.

Dayton

"Weapon System Management in a Decentralized Corporation," I. H. McLarem, Bendix Corp. 9/10/59.

"Progress Report on the Department of Defense AdHoc Committee Study on Electronic Parts and Tube Specification Management for Reliability," A. W. Rogers, Fort Monmouth Signal Corp; E. J. Nucci, Dept. of Defense, Pentagon; R. E. Moe, General Electric Co. 10/1/59.

"Molecular Engineering Philosophy of Electronic System Design," Dr. S. W. Herwald, Westinghouse Electric Corp. 12/3/59.

"Cesium Ion Propulsion," Dr. A. T. Forrester Electro Optical Co. 2/4/60.

(Continued on page 120A)

MINCOM

announces a new double-duty magnetic tape system

the CM-100

records & reproduces **6 SPEEDS**

Greater bandwidths at lower speeds in both analog and pulse recording/reproducing (for example, 500 kc at 60 ips). All in one compact standard rack. Details? Write for brochure.

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FROM
MOTOROLA

INDUSTRIAL TRANSISTORS WITH THE CERTIFIED RELIABILITY OF MILITARY UNITS

Why MOTOROLA Introduced The MEG-A-LIFE Program

In many industrial applications, assurance of semiconductor reliability is as desirable as it is for military applications. For this reason, Motorola has introduced "Meg-A-Life" . . . a quality assurance program patterned after the procedures used for standard military-approved components.

"Meg-A-Life" tests are in accordance with MIL-S-19500 (general military specifications for transistors). Sampling is based upon MIL-STD-105. In addition to electrical, mechanical and environmental tests (including shock, centrifuge, vibration, humidity and temperature tests), 1000-hour storage tests at 100°C and 1000-hour operating life tests at maximum rated power are performed.

Approved units are stored in a *bonded* area. Written certification of compliance to "Meg-A-Life" reliability requirements is available. Since all tests represent the most adverse conditions for which the devices are designed, Motorola's "Meg-A-Life" program provides the industrial user an assurance of reliability previously not available.

FOR COMPLETE INFORMATION on the Motorola "Meg-A-Life" program contact your Motorola Semiconductor district office:

BOSTON 385 Concord Ave., Belmont 78, Mass.	IVanhoe 4-5070
CHICAGO 51, 5234 West Diversey Avenue	AVenue 2-4300
DETROIT 27, 13131 Lyndon Avenue	BRoadway 3-7171
LOS ANGELES 1741 Ivar Avenue, Hollywood 28, Calif.	HOllywood 2-0821
MINNEAPOLIS 27, 7731 6th Avenue North	LIberty 5-2198
NEW YORK 1051 Bloomfield Ave., Clifton, N.J.	GRegory 2-5300
from New York	WIsconsin 7-2980
SAN FRANCISCO 1299 Bayshore Highway, Burlingame, Calif.	DIamond 2-3228
SYRACUSE 101 South Salina	GRanite 4-3321

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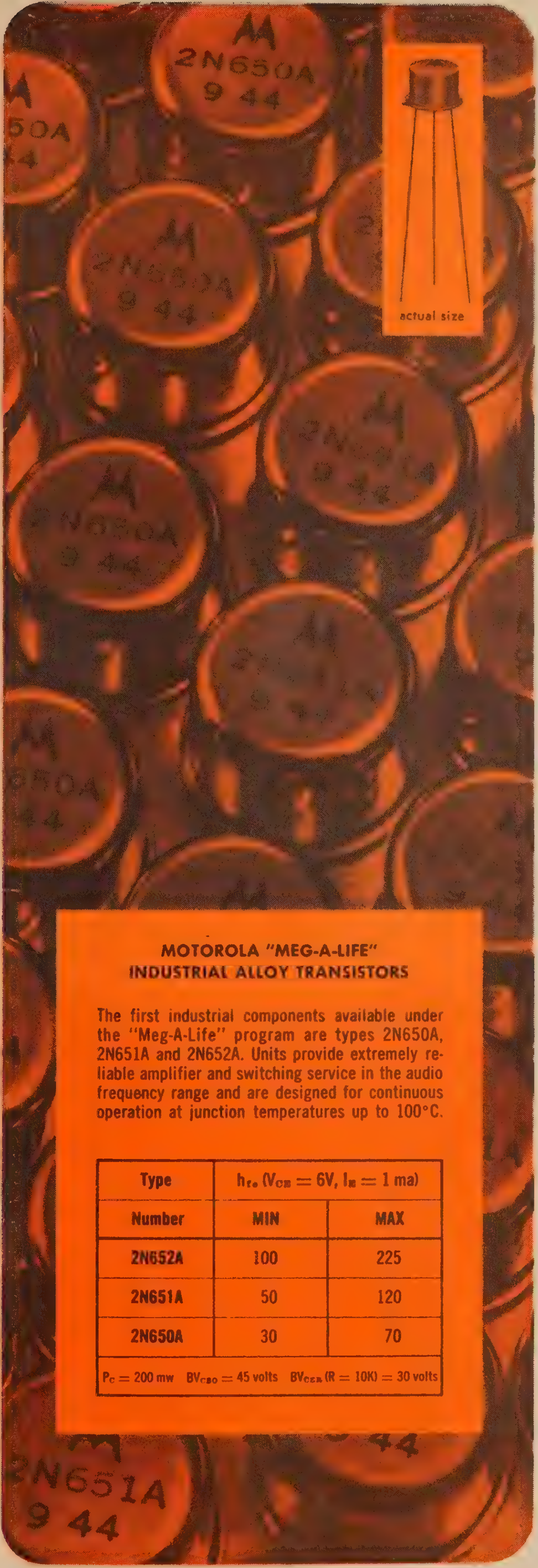

MOTOROLA "MEG-A-LIFE"
INDUSTRIAL ALLOY TRANSISTORS

The first industrial components available under the "Meg-A-Life" program are types 2N650A, 2N651A and 2N652A. Units provide extremely reliable amplifier and switching service in the audio frequency range and are designed for continuous operation at junction temperatures up to 100°C.

Type	h_{fe} ($V_{CB} = 6V$, $I_E = 1$ ma)	
Number	MIN	MAX
2N652A	100	225
2N651A	50	120
2N650A	30	70
$P_C = 200$ mw $BV_{CBO} = 45$ volts BV_{CER} ($R = 10K$) $= 30$ volts		

LOWEST COST PER GRAM

UNLIMITED PRODUCTION CAPACITY

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NEW MATERIAL RESEARCH

SPECIFICATIONS TO ORDER

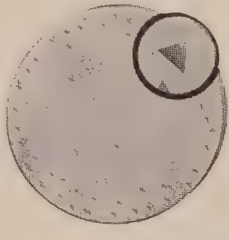
6 good reasons for letting **KNAPIC** grow your Silicon Crystals

KNAPIC specializes in Silicon and Germanium Crystals for Semiconductor, Solar Cell and Infrared uses

Major manufacturers of semiconductor devices have found that Knapic Electro-Physics, Inc. can provide production quantities of highest quality silicon and germanium monocrystals far quicker, more economically, and to much tighter specifications than they can produce themselves.

The reason? Knapic Electro-Physics are *specialists* with accelerated experience in growing new materials to specification.

Why not let us grow your crystals too?



Dislocation density, Knapic silicon monocrystals grown by a modified Czochralski technique: Crystal diameter to ⅜"—None; ⅜" to ¾"—less than 10 per sq. cm.; ¾" to 1¼"—less than 100 per sq. cm.; 1½" to 2" less than 1000 per sq. cm.

Check These Advantages

- ☐ **Extremely** low dislocation densities.
- ☐ **Tight** horizontal and vertical resistivity tolerances.
- ☐ **Diameters** from ¼" to 2". Wt. to 250 grams per crystal. Individual crystal lengths to 10
- ☐ **Low Oxygen content** 1 x 10^{17} per cc., 1 x 10^{16} for special Knapic small diameter material.
- ☐ **Doping** subject to customer specification, usually boron for P type, phosphorous for N type.
- ☐ **Lifetimes:** 1 to 15 ohm cm.—over 50 microseconds; 15 to 100 ohm cm.—over 100 microseconds; 100 to 1000 ohm cm.—over 300 microseconds. Special Knapic small diameter material over 1000 microseconds.

Specification Sheets Available

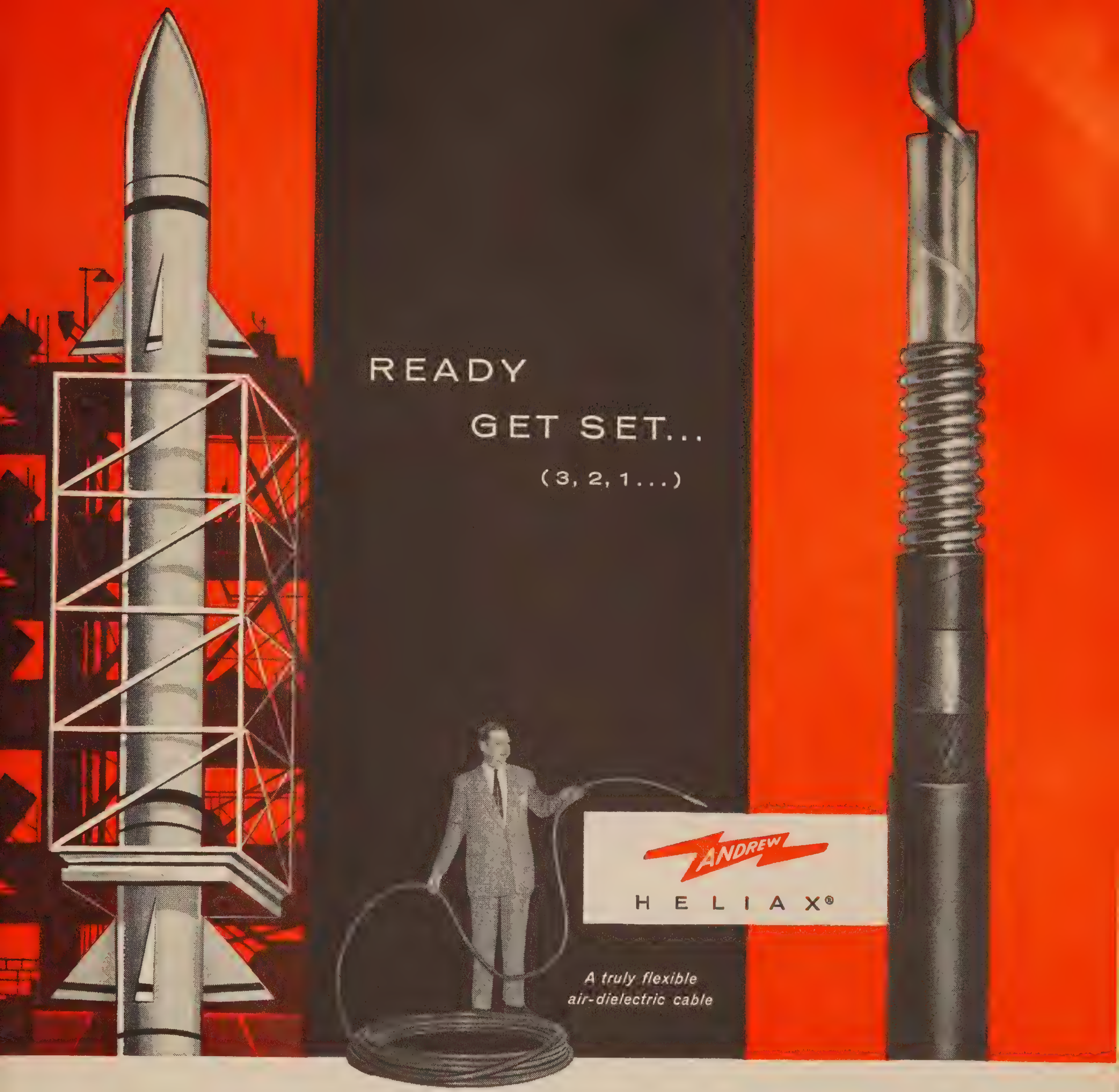
Knapic Electro-Physics, Inc.

936-40 Industrial Ave., Palo Alto, Calif. • Phone DAvenport 1-5544

SALES OFFICES:

Eastern—405 Lexington Avenue, New York, N. Y. • Phone YUkon 6-0360
Western—204 South Beverly Dr., Beverly Hills, Calif. • Phone CRestview 6-7175
European—#2 Prins Frederick Hendriklaan, Naarden, Holland • Phone K 2959-8988

. . . Also manufacturer of large diameter silicon and germanium lenses and cut domes for infrared use



A truly flexible air-dielectric cable

At the zero second everything must function without failure. Andrew Heliax cable is used in postassembly and preflight checkouts of missile radio frequency systems. The cable forms a closed circuit over which interrogation and response signals are transmitted between checkout equipment and airborne radio frequency packages. The Heliax cable runs from a mobile trailer to connecting points on the missile.

The ruggedness of Heliax makes it well suited to this challenging task, where its low VSWR, low RF leakage and low attenuation give accurate measurement of systems performance. Flexibility permits the cable to be taken down, recoiled and subsequently reused many times.

If you require similar characteristics in a cable, consider the special advantages of Heliax.

Heliax is normally supplied as an assembly, complete with end fittings factory attached, reducing installation labor and improving quality.

Complete uniformity throughout its entire length gives Heliax *superior* electrical characteristics.

Heliax is always less difficult, less costly to install, *easier to handle.*

Heliax is available in ⅞"size (Type H0) and 1⅝" size (Type H1).

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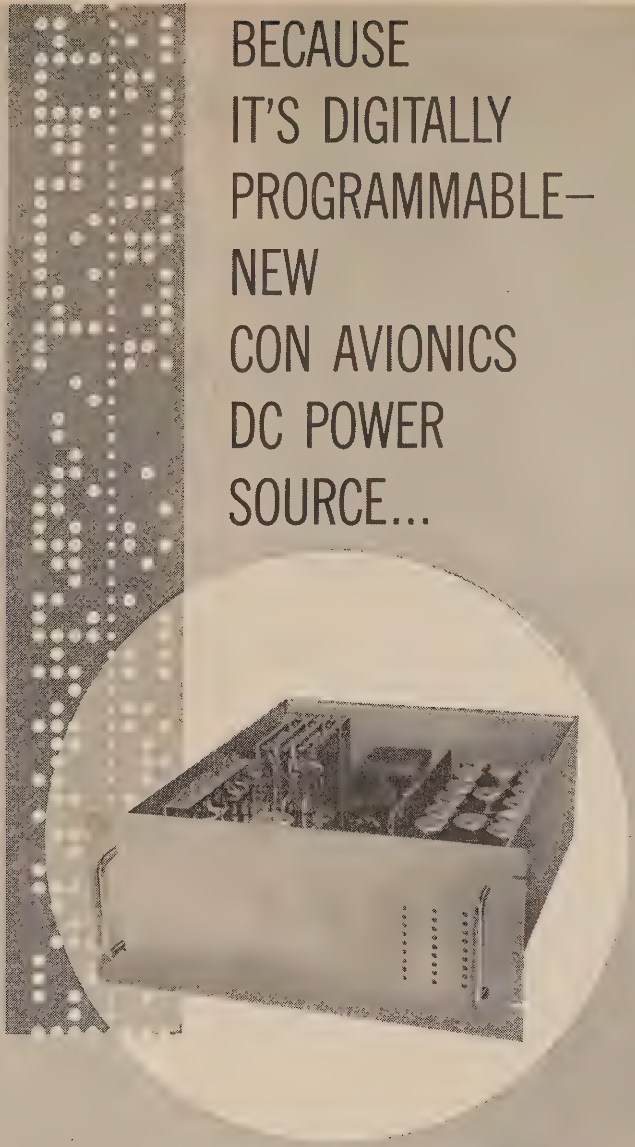

BECAUSE IT'S DIGITALLY PROGRAMMABLE— NEW CON AVIONICS DC POWER SOURCE...

...INSTANTLY PROVIDES ON COMMAND ANY VOLTAGE FROM 0.1 TO 50 VOLTS DC—UP TO 15 AMPERES

Another first by Con Avionics, this digitally programmable power source translates manual push-button setting or output of your program device into the selected voltage. It can be made to respond to any digital code from sources such as paper or magnetic tape readers, punched card readers, or keyboards. Voltages may be changed from any setting to any other within 300 milliseconds. Voltage is stable and accurate within ±0.1% of the selected value. Ripple is less than 0.05% rms.

The completely self-contained design of the Con Avionics DC Power Source eliminates external rheostats, step switches and other devices. This unit reduces equipment complexity in data systems, automatic checkout equipment or precision testing applications. Outstanding results are obtained both in the lab and on production work.

CONSOLIDATED AVIONICS CORPORATION
A SUBSIDIARY OF CONSOLIDATED DIESEL ELECTRIC CORPORATION
800 Shames Drive • Westbury, L. I. • EDgewood 4-8400

Section Meetings

(Continued from page 116A)

DETROIT

"Simulation of Nervous System Processes with Artificial Neurons," L. D. Harman, Bell Telephone Labs.; 2/19/60.

EGYPT

"Non-destructive Testing of Materials Using X-Ray and Ultrasonics," Dr. R. O. Schumacher, Philips-Hamburg Co., Germany. 2/5/60.

ERIE

"IRE Activities," Dr. R. L. McFarlan, 10/1/59.

FLORIDA WEST COAST

"Strontium 90, Skeleton in the Closet," Dr. Louis Polskin. Private Physician. 2/17/60.

FORT HUACHUCA

"Motorola Commercial Two-way Communication Systems," John Byrne, Motorola, Inc. 2/29/60.

FORT WORTH

"Low Frequency Active Filters," Gifford White, White Instrument Labs. 2/9/60.

HOUSTON

"Printed Circuits for Motors and Missiles," John Calpera, Photocircuits Corp. 2/23/60.

HUNTSVILLE

"Design of Phase Lock Receivers," Arthur Kline, Motorola, Inc.; 2/24/60.

INDIANAPOLIS

"Power Transmission Without Wires Using Microwaves," Dr. R. L. McFarlan, President of the IRE. 2/26/60.

"Science and Engineering in Modern Society," Dr. R. L. McFarlan, President of the IRE 2/27/60.

LONDON

"The World's Sources of Energy," Dr. Robert Uffen, University of Western Ontario. 3/8/60.

Students Night. Five contestants as follows:

"100 KV Proton Accelerator"—Roy Kochlen, 1st prize
"A Logical Switching Demonstration"—Gus Leipens, 2nd prize
"Traveling Wave Tubes"—Ed Hartlin, 3rd prize
"Pressure Pulse Measurements"—Bob Johnson
"Microwave Optics"—Dave Boyle 2/9/60.

LUBBOCK

"Microwave Applications," Larry Pease, Southwestern Bell Telephone Co. 2/23/60.

MONTREAL

"Tropospheric Extended Range Transmission," S. A. Stone, National Research Council. 2/17/60.

NORTHERN ALBERTA

"The IRE and Canada," A. P. H. Barclay, Director Region VIII. 2/22/60.

NORTHWEST FLORIDA

"The Use of Microwave Energy to Support Space Platforms," Dr. R. L. McFarlan, President of the IRE. 2/10/60.

(Continued on page 124A)

ANOTHER FAIRCHILD FIRST

THE UNIVERSAL TRANSISTOR

FAIRCHILD'S 2N1613

DIFFUSED SILICON PLANAR TRANSISTOR

GUARANTEED USEFUL BETAS FROM 100μA to 0.5A:

15 @ .1mA 20 @ 1mA 30 @ 150mA 15 @ 500mA

Guaranteed minimum Beta over a 5.000 to 1 range of collector current makes the 2N1613 the most versatile transistor presently on the market

WIDE RANGE OF APPLICATIONS: in Fast Switching (logic and high current): Amplifiers (low level, low noise, wideband, VHF power).

RELIABILITY IN A NEW DIMENSION: The Planar Transistor is the most thoroughly proven transistor ever introduced commercially, with over 5,000,000 transistor hours plus 300°C. stabilization on all units.

TENTATIVE SPECIFICATIONS— FAIRCHILD 2N1613

f_t typical	100 mc
P_C @ 25°C. Case Temperature	3W
h_{FE} (see Beta paragraph above)	Min 30
V_{CER}	40V
V_{CBO}	75V
V_{BE}SAT. (Max.)	1.3V
V_{CE}SAT. (Max.)	1.5V
I_{CBO} @ 25°C. (Max.) measured at 60V	25mμA

SOME IMPORTANT PARAMETERS: 7 db — Noise Figure: 100 megacycles—Gain-bandwidth product. 0.0005μA I_{CBO} typical at 60V, 25°C.

IMMEDIATE AVAILABILITY: Quantities from 1-999 from franchised Fairchild distributors at factory prices.

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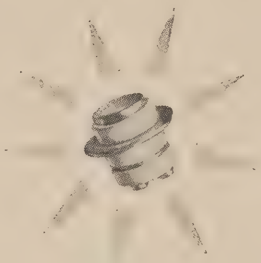
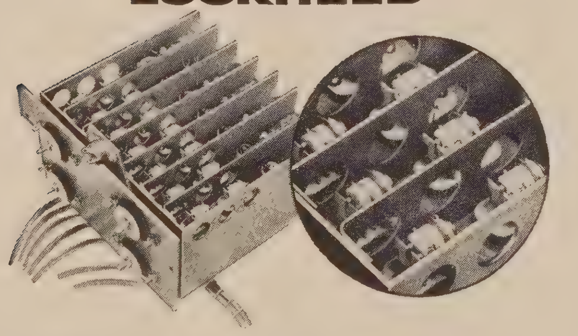
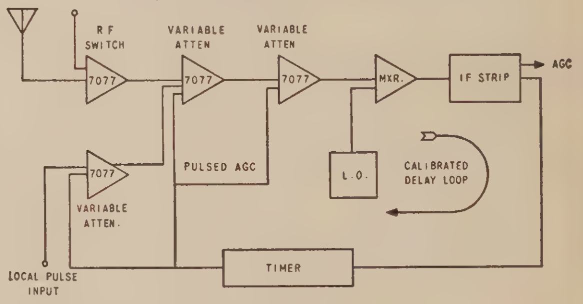


G-E 7077
over a wide spectrum o

LOCKHEED



MOTOROLA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PULSED AGC
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CALIBRATED DELAY LOOP
VARIABLE ATTEN.
LOCAL PULSE INPUT
TIMER

WIDE-BAND TAPE RECORDER.

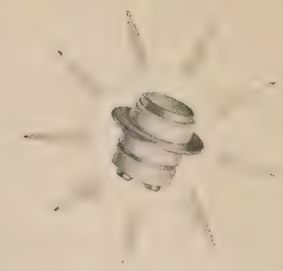
For Lockheed, California Division, 28 General Electric 7077's serve as pre-amplifiers in a 14-channel 500-kc 60"-per-second tape recorder that stores wide-band information from an air defense exercise five times as rapidly as before. Extreme requirements of frequency, timing accuracy, and reproducibility are met by the 7077's low noise, high impedance, and high G_m. Also, the tube's small size matches the miniaturization needs of the Lockheed tape-recorder equipment.

GROUND-SURVEYING RADAR.

Motorola's Western Military Electronics Center in Phoenix uses four General Electric ceramic 7077's for high-speed RF switching and pulse attenuation in a 440-mc distance measuring circuit where timing to *one billionth of a second* is needed for pulse delay measurement. Minimum plate-to-cathode capacitance, high gain, low noise, and a configuration that makes the tube ideal for grounded-grid service, were reasons back of Motorola's choice of the G-E 7077.

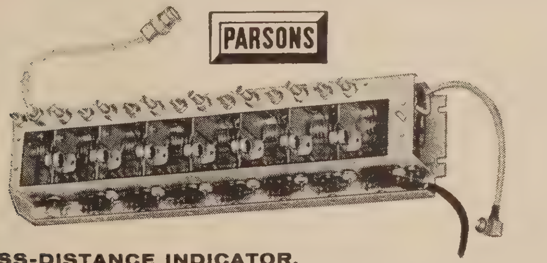
nvolves trade-offs...but

using ceramic tubes.



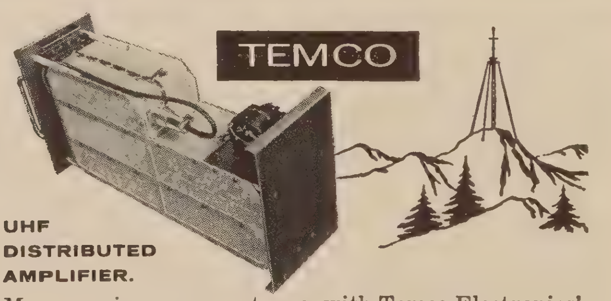
meets designers' targets

frequency and function.



MISS-DISTANCE INDICATOR.

Ralph M. Parsons Company uses seven General Electric ceramic 7077's in tuned stages as high-gain, low-noise RF amplifiers in its PARAMI system for determining air-intercept missile accuracy. A 324-mc circuit, the Parsons PARAMI system has a gain-bandwidth product approaching the limit of the state of the art.



UHF DISTRIBUTED AMPLIFIER.

Many receivers—one antenna, with Temco Electronics' broadband distributed amplifier. Arranged in six five-stage units, 30 G-E 7077's are used as RF amplifiers, operating over a 750 mc bandwidth, between 250 and 1000-mc. Fills the frequency gap between TWT's and existing distributed amplifiers.

Phone your nearest General Electric Receiving Tube Department Office:

New York: WIsconsin 7-4065, 6, 7, 8 **Chicago: SPring 7-1600** **Los Angeles: GRanite 9-7765**

Progress Is Our Most Important Product

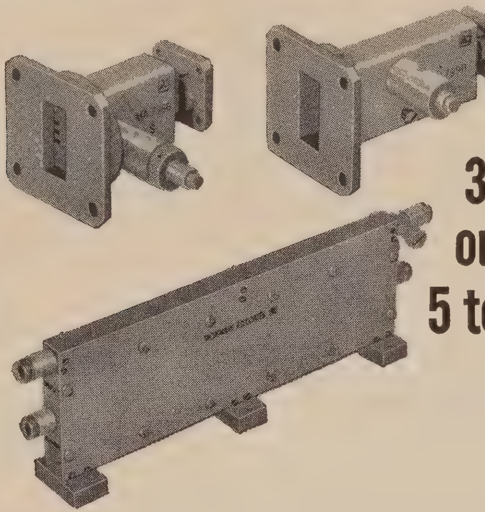
GENERAL ELECTRIC

431-202

UNPRECEDENTED EFFICIENCIES IN HARMONIC GENERATION . . .

11 kMc input @ 500 mw

33 kMc output @ 5 to 20 mw



Nine new examples of Microwave Associates' capabilities in the design of harmonic generators are available now. These models feature exceptionally high output power with conversion losses well below existing devices.

New designs incorporating solid state elements can be used to eliminate costly klystrons, DC bias supplies and high voltage power supplies. All units feature broadband fixed-tuned operation, filters eliminating unwanted harmonics, and versatile coaxial, waveguide and strip-line packaging.

These models are typical examples of our progress to date . . . presently we are working for even greater efficiencies and performance. Additional models in development converting 1 watt at 2000 Mc to 100 mw or more, at 4000 and 6000 Mc, to be announced soon.

Your specific application problems are of prime interest to us. Our Applications Engineers would welcome the opportunity to design harmonic generators to meet your specifications.

SPECIFICATIONS

	INPUT				OUTPUT				
Model	Connector Type UG-	Frequency Input kMc/s	Band	mw input	Connector Type UG-	Frequency Output kMc/s	Band	Conversion Loss (max.)	Output mw
MA796	23/U	0.26 — 0.28	P	20	23/U	1.30 — 1.43	L	13db	1
MA797	23/U	1.30 — 1.43	L	100	23/U	5.22 — 5.72	C	15db	3
MA798A	39/U	9.0±150Mc	X	500	596/U	18.0±300Mc	K	17db	10
MA798B	39/U	10.0±150Mc	X	500	596/U	20.0±300Mc	K	17db	10
MA798C	39/U	11.0±150Mc	X	500	596/U	22.0±300Mc	K	17db	10
MA798D	39/U	12.0±150Mc	X	500	596/U	24.0±300Mc	K	17db	10
MA799A	39/U	9.0±100Mc	X	500	600/U	27.0±300Mc	Ka	20db	5
MA799B	39/U	10.0±100Mc	X	500	600/U	30.0±300Mc	Ka	20db	5
MA799C	39/U	11.0±100Mc	X	500	600/U	33.0±300Mc	Ka	20db	5

Write or call:

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BURLINGTON, MASSACHUSETTS

Western Union FAX-TWX: Burlington, Mass., 942 • BRowning 2-3000

Section Meetings

(Continued from page 120A)

ORLANDO

"Navigation and Communication Systems and Future Communications," H. Scarborough, I.T.T. Labs. 2/17/60.

OTTAWA

"Tunnel Diodes," Dr. John Simpson and Mr. Pulford of the National Research Council, Ottawa. 3/3/60.

PHILADELPHIA

"The IRE and Its Relation to Medical Sciences," Dr. R. L. McFarlan, President of the IRE. 3/20/60.

PITTSBURGH

Presentation of Fellow Award by Dr. R. L. McFarlan, IRE President. 3/2/60.

"Low Noise Solid State Microwave Receivers," Dr. R. D. Haun, Jr., Westinghouse Research Laboratories. 3/7/60.

PRINCETON

"Some Recent Developments in Infrared and Their Application to Missiles," Eric Wormser, Barnes Engineering Co. 1/14/60.

"Electrical Control of the Brain," Dr. Jose Delgado, Yale School of Medicine. 2/11/60.

REGINA

"Description of Video System," L. McBride, CKCK-TV; "Filters," Dr. D. V. Tilston, Sinclair Radio Labs. 1/16/60.

"Present Day Electronics," A. P. H. Barclay, Director Region VIII. Tour and display of R.C.M.P. Crime Detection Lab. 2/17/60.

RIO DE JANEIRO

"Automatization of the Telephone Service in the Area of Borda do Campo," Dr. V. Martins, Comp. Tel. da Borda do Campo. 3/9/60.

ROCHESTER

"Cold Cathode Tubes," Dr. M. Skellett, Tung-Sol Electric, Inc. 9/24/59.

"TASI—Time Assignment Speech Interpolation," E. F. O'Neill, Bell Telephone Labs. 12/3/59.

"Who's Ahead in the Battle of the Sexes—Or—How to Play Both Sides in Stereo," A. G. Schifino, Stromberg-Carlson. 12/8/59.

"Christmas Message," Dr. A. S. Turnipseed, Pastor, First Methodist Church. 12/15/59.

SAN ANTONIO-AUSTIN

"The Log-Periodic Antenna," C. R. Graf, USAF Security Service. 2/19/60.

SAN DIEGO

"Soviet Computing Technology 1959," Dr. W. H. Ware, The Rand Corp. 3/2/60.

SYRACUSE

Presentation of Fellow Awards. 3/3/60.

TOKYO

"Miscellaneous History on Radio Waves," Dr. Shogo Namba, Kokusai Denshin Denwa Co. Presentation of Fellow Award. 2/1/60.

TORONTO

Field Tour of Radio Valve Co., Ltd. 11/23/59.

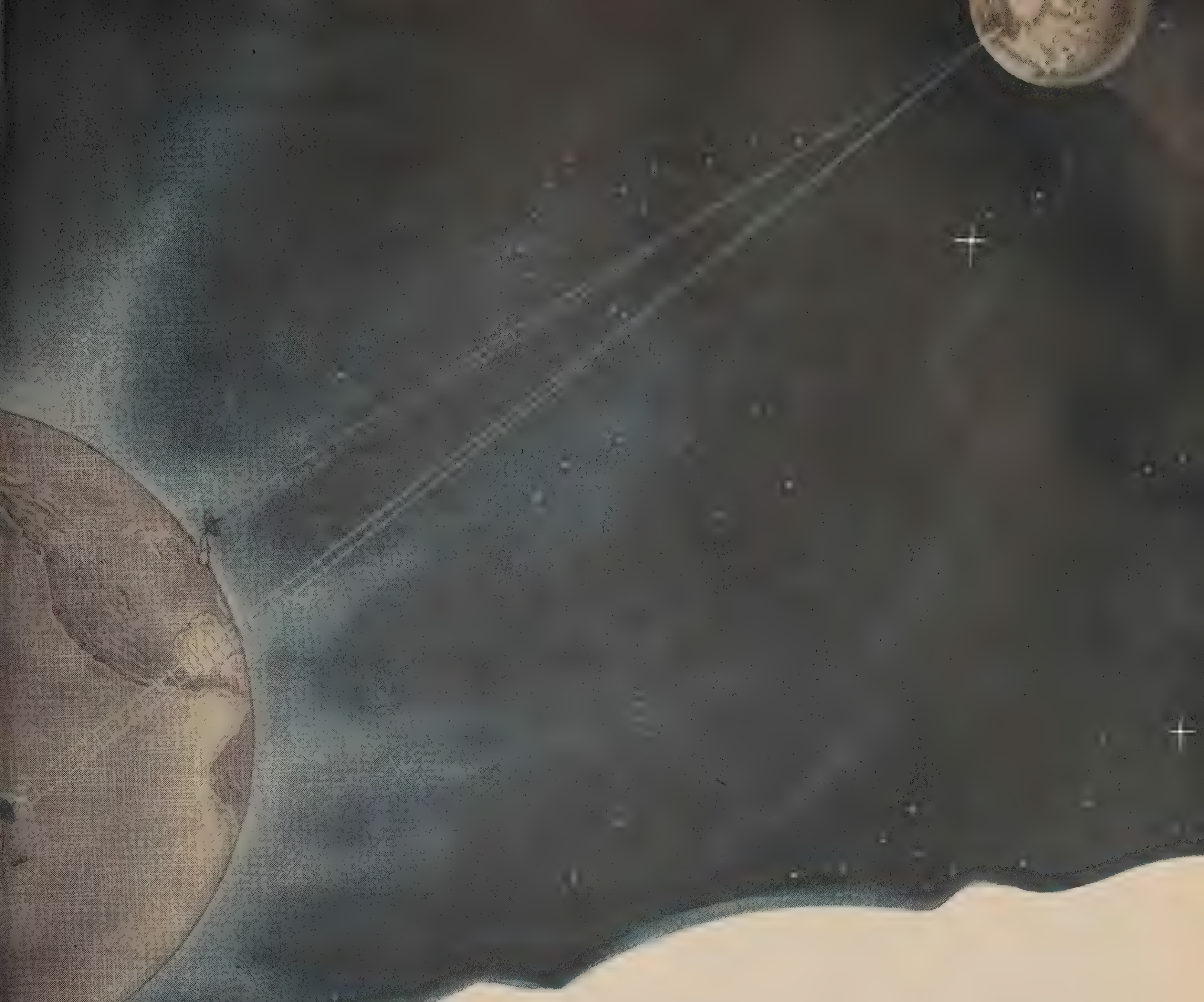
"Tubes Versus Transistors," D. S. Simkin and J. H. Beardall, Philips Electronics Industries, Ltd. 12/14/59.

Field Tour of Maclean-Hunter Printing Plant, Toronto. 1/12/60.

"Students Night." 2/18/60.

"Backstage Impressions of the CBS.," F. Davis, CBS. 3/7/60.

(Continued on page 128A)



WASHINGTON TO HAWAII VIA OUTER SPACE!

Right now the Navy's "moon bounce" transmitter is operational . . . virtually jamproof against enemy and immune to ionospheric storms.

Essentially, the Navy's "Communications Moon Relay" is a 4-channel multiplexed teletypewriter-facsimile circuit between Washington and Pearl Harbor via the moon. The narrow beam, highly directionalized L-Band signal pulses travel to the moon and bounce back to the receiver in $2\frac{1}{2}$ seconds . . . utilizing a half million mile signal path to span 5,000 miles!

Continental Electronics' transmitter is 100 KW, conventional transmission, and is unusual for the high level of continuous power used. Each Transmitter-Receiver site uses an equatorially mounted, high gain, fully steerable dish-type antenna 84 feet in diameter, aimed at the moon by astronomical data.

When fully developed, this communications system opens a whole new spectrum of radio communications for our overcrowded Long Range Communications; the number of channels that can be carried by time-sharing on a single antenna is readily expanded.

Another
inental Electronics
Contribution
uper Power Radio

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-Altec Electronics, Inc.

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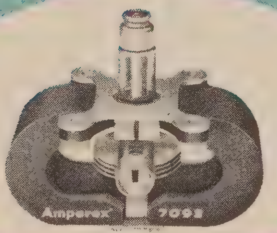
THE SHORTEST PULSE ON RECORD...

GENERATED BY THE NEW
Amperex®
TYPE 7093 K-BAND MAGNETRON



The 7093 permits the design of an extremely compact, short range radar system providing resolution of 4 meters at 1000 yards and a minimum range of only a few yards.

NOTEWORTHY FEATURES OF THE AMPEREX TYPE 7093

Frequency Range: 34,512 - 35,208Mc.
Power Output: 25KW
Pulse Length: 0.02 microseconds
Rise Time: 600KV per microsecond
Weight: 4.2 lbs.
Cathode: Philips dispenser-type
Immediately available in production quantities.

Illustration above is a direct line-conversion from an unretouched radarscope photo of Schiphol Airport, Amsterdam, Netherlands. Range—1500 meters. **1** *jeep traveling down runway at 55 mph.* **2** *slow moving vehicles and people walking.*

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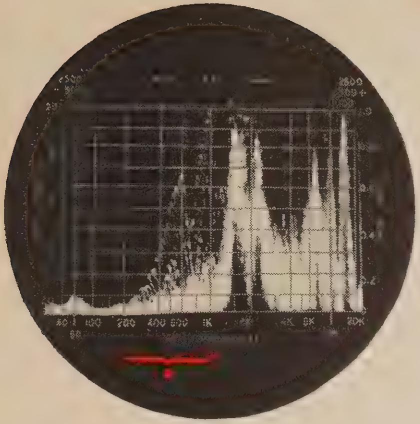
PANORAMIC LP-1a
SONIC SPECTRUM ANALYZER
20 cps-22.5 kc.



"Coast-down" analysis of Gyro Motor by Model LP-la Spectrum Analyzer. Area A shows decreasing fundamental frequency, resonant rise and decay, and vibration components over 60 successive scans in one minute.

The Model LP-1a "quick-look" helps locate and evaluate discrete or random signals *faster* and *easier* by scanning the entire spectrum logarithmically from 40 cps to 20 kc. Once every second it automatically separates, measures and plots the frequency and voltage of waveform components on the calibrated X and Y axes, respectively, of a long persistence 5" CRT.

For very detailed analysis, linear segments 40 to 5000 cps wide, centerable between 0 and 20 kc, may be magnified on the screen.

Amplitude ratios of up to 40 db can be simultaneously measured.

High sampling rate and panoramic displays assure

1. **Minimum risk of missing weak signals or spectrum holes.**
2. **Fast measurements by eliminating slow point by point plots.**
3. **Simultaneous measurement of signals with widely divergent amplitudes and/or frequencies.**
4. **Continuous analysis of rapid changes in spectral content or design parameters.**

Proved in hundreds of research, design and production installations, the LP-1a is a valuable tool for Noise and Vibration analysis • Harmonic and IM measurements • General waveform studies • Power Spectral Density Analysis • Response Curve Tracing

SUMMARY OF SPECIFICATIONS:

Frequency Range: 20 cps—22.5 kc.
(1) Preset linear frequency scans: any segment width of 200, 1000, 5000 cps centerable from 0-20 kc; Variable from 40 cps to 5000 cps with Auxiliary Function Unit C.
(2) Preset Log Scan—40 cps to 20 kc.

Frequency Scales: Linear and Log

Center Frequency Control: Calibrated 0-20 kc (used on lin scan)

Dynamic Range: 60 db

Amplitude Scales: Linear and 2 decade log (Expandable to 60 db)

Sensitivity: 500 μv to 500 v for full scale linear deflection

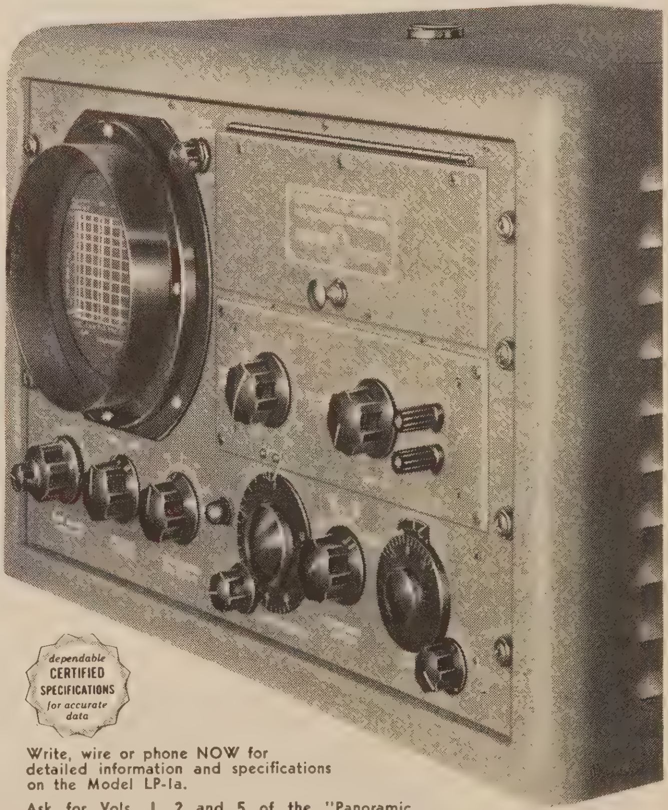
Voltage Accuracy: Lin Sweep (40 cps—22.5 kc): ±5% or ±0.5 db. Log Sweep (40 cps—20 kc): ±10% on lin. ampl. scale, ±1.5 db on log ampl. scale.

Scan Rate: 1/sec., internally generated; adjustable with accessory equipments

Resolution: For log scan, automatically optimized. For lin scan, preset 30, 75 and 170 cps at 200, 1000 and 5000 cps sweepwidth, respectively. Variable from 10 cps to 1 kc with Auxiliary Function Unit C.

HIGHLIGHT FEATURES:

- **1-sec. "quick-look" at entire spectrum (40 cps–20 kc)**
- **Magnified analysis on reduced sweep widths**
- **Direct reading frequency–selective voltmeter**
- **Exceptionally stable circuitry: better than 5 cps/hr.**
- **Economical**
- **Simple Operation**



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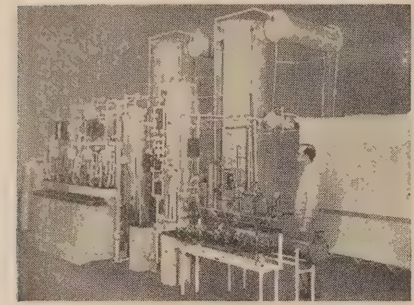
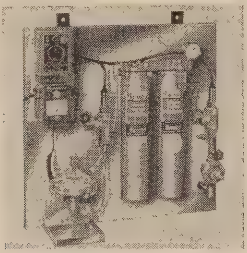
BARNSTEAD ENGINEERED WATER PURIFICATION EQUIPMENT



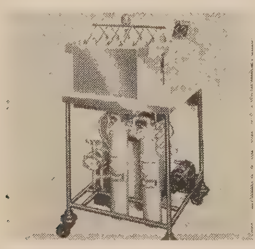
18,000,000 OHM WATER

This Barnstead equipment engineered in series consists of sand and carbon filter, high-capacity four-bed demineralizer, two Barnstead High-Purity Stills, Tin-lined tank, Mixed-Bed Demineralizer, MF Submicron Filter, Tin-lined Heater. Produces 18,000,000 ohm water in production quantities, completely free of minerals, organics, bacteria, and submicroscopic particles down to 0.45 micron.



COOLING WATER RE-PURIFYING SYSTEM

adds thousands of hours to UHF transmitting tube life. Saves additional hours of maintenance ordinarily spent in citric acid cleaning procedures within the cooling system. Write for detailed Bulletin 149.



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Rinses transistors, diodes, and other small components in hot, ultra pure water. System filters out particles to 0.45 micron. Continuous re-purification system conserves water resulting in substantial savings. Write for Bulletin 146.

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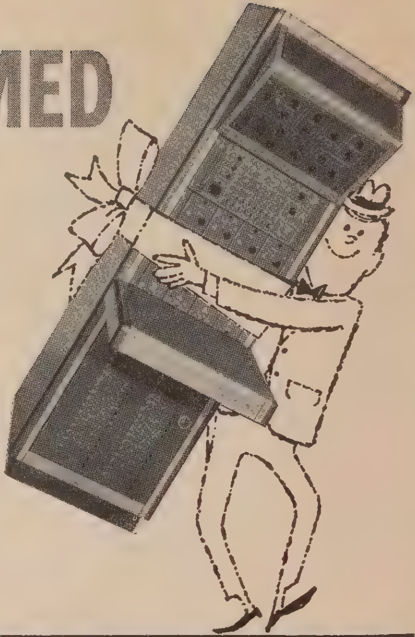

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MAGNETIC CORE TESTERS • HIGH SPEED MEMORIES • LOGIC CIRCUIT PLUG-INS

Section Meetings

(Continued from page 124A)

TUCSON

"Relativity, Atomic Clocks and Satellites," Dr. H. Lyons, Hughes Aircraft Co. 2/18/60.

TULSA

"Modern Stereo," P. W. Klipsch, Klipsch & Associates. 2/18/60.

VIRGINIA

"The Day The Earth Tumbles," C. P. Thomas, Hughes Aircraft Corp. 1/22/60.

"Project Mercury," G. V. Graves, NASA. 2/12/60.

WESTERN MASSACHUSETTS

"The Frontiers of Space," T. Mehlin, Williams College. 2/17/60.

WICHITA

"Your Institute of Radio Engineers," C. E. Harp, University of Oklahoma. 1/20/60.

"Electronic Switching," W. B. Quirk, Bell Telephone. 2/18/60.

WILLIAMSPORT

"State Police Radio," Lt. R. Bomboy, Pennsylvania State Police. 2/24/60.

WINNIPEG

"Electronics and the IRE," A. P. H. Barclay, Director Region VIII. 2/15/60.

(Continued on page 130A)

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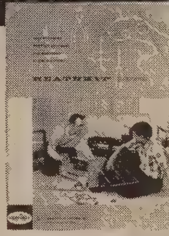

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Featuring face plate radius of 150 inches minimum and High Resolution Capabilities

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AVAILABLE WITH ONE OF THE FOLLOWING THREE GUNS

- **Magnetic Focus Gun** . . . gives uniform line width across entire tube.
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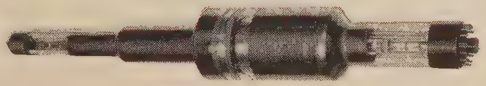
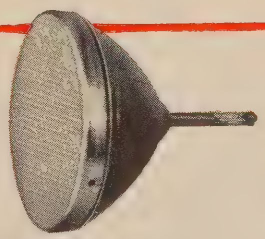
- **Magnetic High Resolution Gun** . . . capabilities exceeding the electrostatic gun.

Rauland research makes possible these remarkably advanced Radar Display Tubes. Their Flat Face feature assures minimum parallax error, and their high resolution affords maximum display accuracy.



SIGNAL STORAGE TYPE TUBE—Has resolving capability of 1000 TV lines, half-tone presentation and storage characteristics variable from a few seconds to several minutes.



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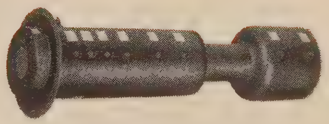

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An engineer talks shop in the

New York World-Telegram

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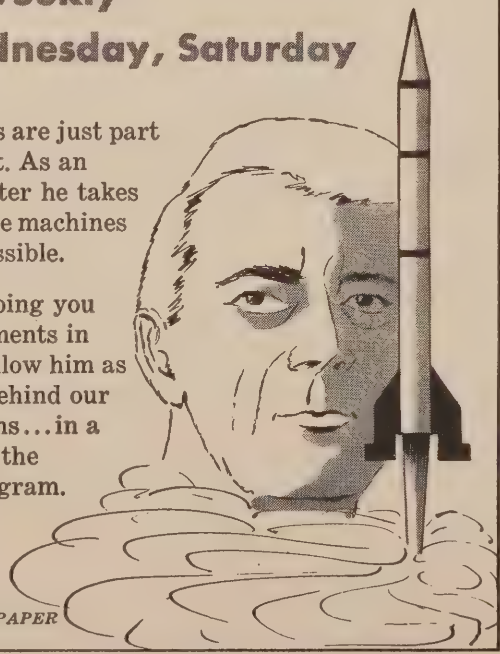
Rockets and computers are just part of Dick Slawsky's beat. As an engineer turned reporter he takes a lot of time to cover the machines that make miracles possible.

But his big job is keeping you posted on the developments in engineering today. Follow him as he reviews the facts behind our scientific breakthroughs... in a terse, timely column in the New York World-Telegram.



A SCRIPPS-HOWARD NEWSPAPER

Section Meetings

(Continued from page 128A)

SUBSECTIONS

BUENAVENTURA

"Automation in Medicine," Robert Martin, Systems Development Corp. 2/17/60.

EAST BAY

"Recent Electronic Experience at Saclay, France"; "Recent Work on Photo Multipliers," Q. A. Kerns, Lawrence Radiation Lab. 2/15/60.

FAIRFIELD COUNTY

"State of the Art in the Field of Receivers as Pertains to Weak Signal Reception," F. S. Harris, Microwave Associates. 2/25/60.

KITCHENER-WATERLOO

"Parametric Amplifiers," Dr. J. L. Yen, University of Toronto; Demonstration of Parametric Amplifiers by S. Demitrevsky, University of Toronto. 2/22/60.

LANCASTER

"The Significance of Military Communication Satellites," C. D. May, Jr., Army Communication Service, Washington, D.C. 1/21/60.

LEHIGH VALLEY

"Facilities and Functions of the New Bethlehem Steel Company Research Laboratory," J. S. Marsh, Bethlehem Steel Co. 1/8/60.

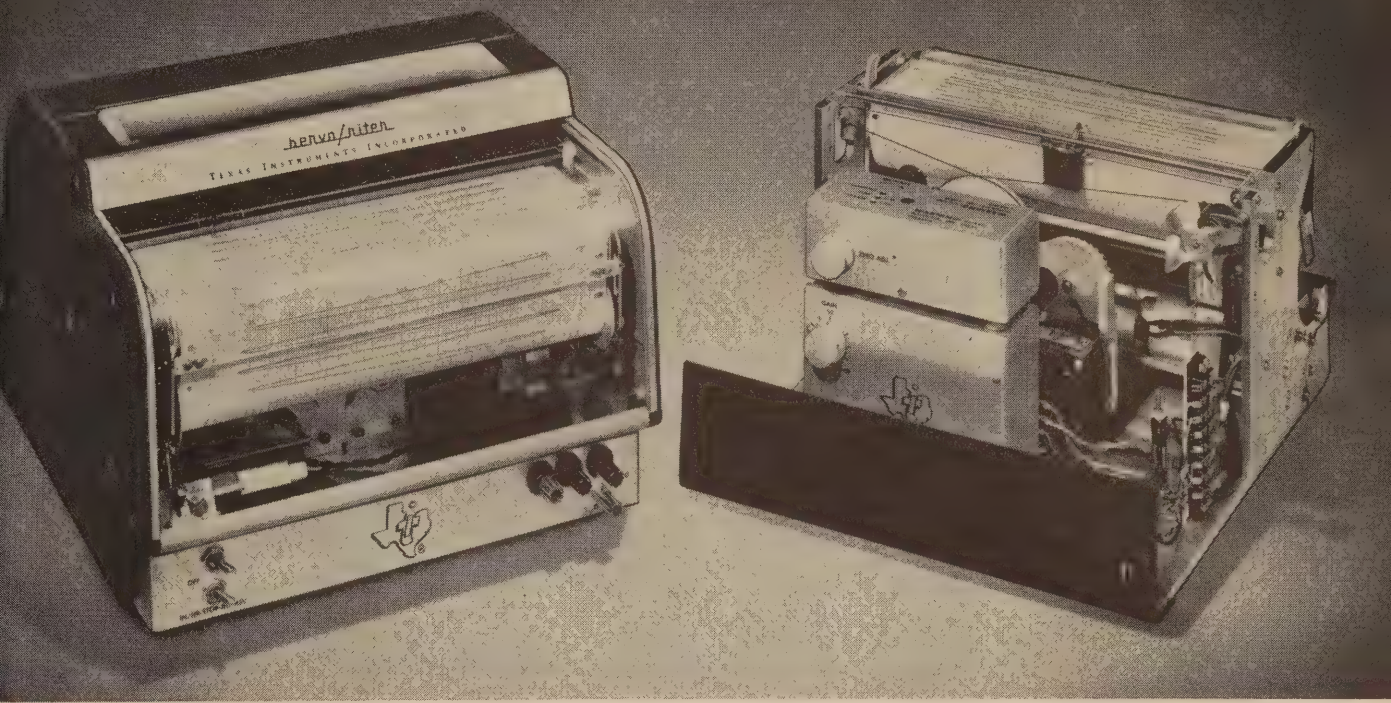
"Inertial Guidance and Space Navigation," G. C. Anderson, North American. 2/24/60.

(Continued on page 132A)

NEWEST way to write performance . . .

servo/riter*

SELF-BALANCING POTENTIOMETRIC RECORDER



OFFERS YOU MORE HIGH PERFORMANCE FEATURES THAN ANY OTHER RECORDER . . . at any price!

The old cliché, "You can pay more but you can't buy better" was never more applicable than in the new "servo/riter" recorder. Texas Instruments has developed a self-balancing potentiometric recorder that incorporates *premium* engineering refinements, sensitivity, reliability and quality construction as *standard* equipment.

High-Sensitivity — Standard electrical span of 2.5 millivolt d-c with off-balance input resistance of 4 megohms gives a power sensitivity of better than 10^{-17} watts.

Fast Pen Speed — Span step response is less than 0.5 second.

High Interference Rejection — Good filtering provides high orders of rejection to common-mode d-c and all types of 60 cps interference. Guard shields permit making full-accuracy measurements at hundreds of volts above ground.

Long-Term Reliability — Tube life is prolonged by heat-dissipating shields. Amplifier gain is stabilized by partial negative feedback. Non-lash, non-wearing, toothed belt drive gives long consistent performance.

Superior Operating Conveniences — Recorder function is easily changed by plug-in input units. Presently standard are 2.5, 5, or 10 millivolt d-c electrical spans . . . special applications and ranges are easily accommodated. "Micrometer" control for zero adjustment and main amplifier gain control are readily accessible as are all other adjustments, connections, and controls. The popular 10-speed chart gears and the high-capacity, easy-prime ink handling system proved on the "recti/riter"® recorder are standard equipment on the "servo/riter" recorder.

There are four "servo/riter" recorder models to choose from . . . *Single Channel, Narrow Grid; Single Channel, Wide Grid; Dual Channel, Narrow Grids; and Dual Channel (overlapping pens), Wide Grid.* Write for technical literature and TI engineering assistance in your specific end or OEM use.

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The new "servo/riter" recorder is a companion to the proved "recti/riter" recorder.

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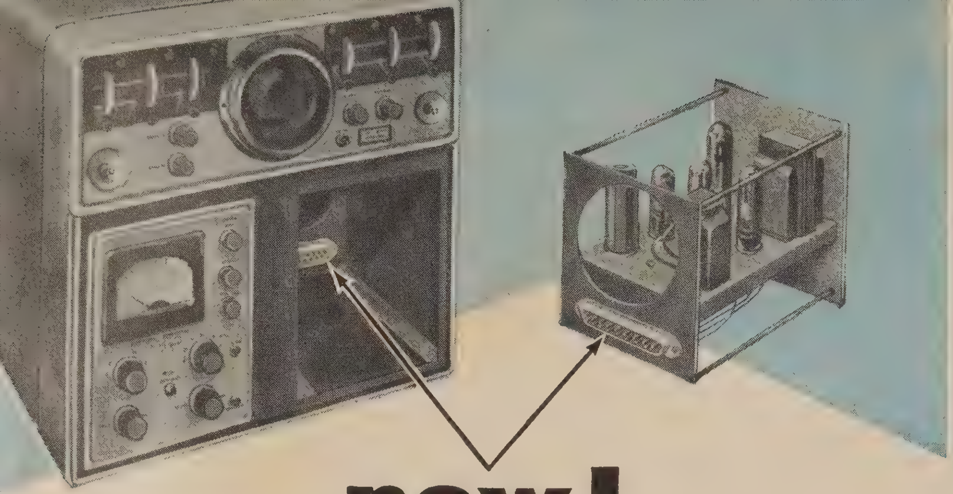


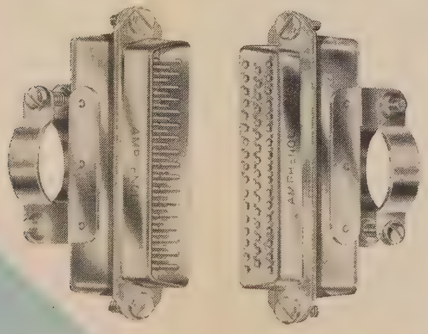
new!

MinRac 17

miniature rack & panel connectors with POKE-HOME® contacts

Solve space, weight and size problems with AMPHENOL's new Min Rac 17 connectors, true miniatures with the "Big Plus" advantage of Poke Home contacts! Min Rac 17's are rack & panel connectors ideally suited for today's compact chassis designs, connectors half the size and weight of standards, delivering full size efficiency. And with the patented Poke Home contact concept (U.S. Pat. 2,419,018), Min Rac 17's are easily, reliably assembled—contacts are crimped or soldered outside the connector body, then "poked home" for assembly.

Min Rac 17's are available in 9, 15, 25, 37 and 50 contacts in rack & panel, cable-to-chassis and cable-to-cable designs. Contacts are gold plated. Shells may be ordered with clear chromate or gold iridite finish.



These remarkable connectors are available now—write for full catalog!

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Section Meetings

(Continued from page 130A)

MEMPHIS

"Engineering-Science Teaching as a Career," J. Freymuth, Southwestern at Memphis. 2/25/60.

MERRIMACK VALLEY

"The Hawk Missile System," J. J. Kirby, Raytheon Co. 2/15/60.

NORTHERN VERMONT

"Progress Report—Space Technology," D. E. Mullen, General Electric. 2/23/60.

SANTA ANA

"The Engineer's Status to His Company, the Profession and His Community," Panel discussion by I. J. Kaar and E. E. Ferry of Hoffman Electronics Corp., and Arthur Curtiss, RCA. 2/24/60.

SANTA BARBARA

"Monstrous Growth in High Energy Physics," Dr. H. Bradner, University of California. 1/22/60.

"Millimetric Waves," J. Markin, Raytheon Co. 2/24/60.

WESTERN NORTH CAROLINA

"Properties of Teflon," J. P. Shoffner, Dupont. "Teflon Fabrication and Applications," B. Ely, Pennsylvania Fluorocarbon Co. 2/26/60.

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10 TO 60 MILLIWATT SENSITIVITY!
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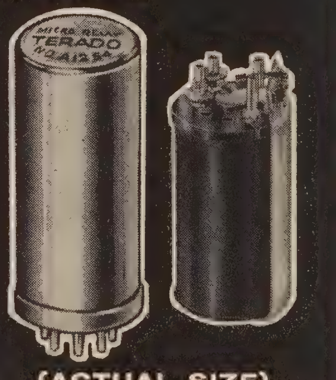
terado MICRO RELAY
For Tube or Transistor Circuits.
Hermetic Seal
Plug in or Terminals



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- 60 Milliwatt Nominal (Special to 10 Milliwatt)
- Rating—1 Amp., 24 V. Non-Inductive
- 24 to 10,000 Ohm Coils
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- Built to Match Your Circuit

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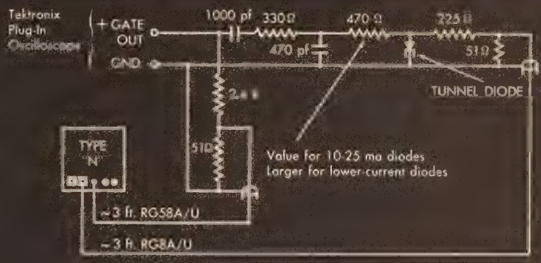
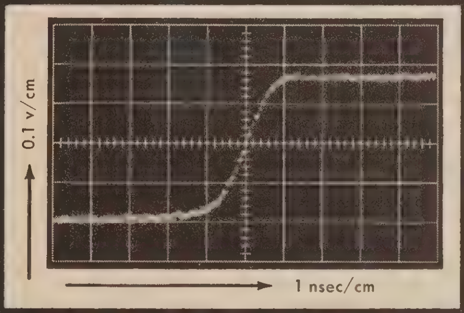
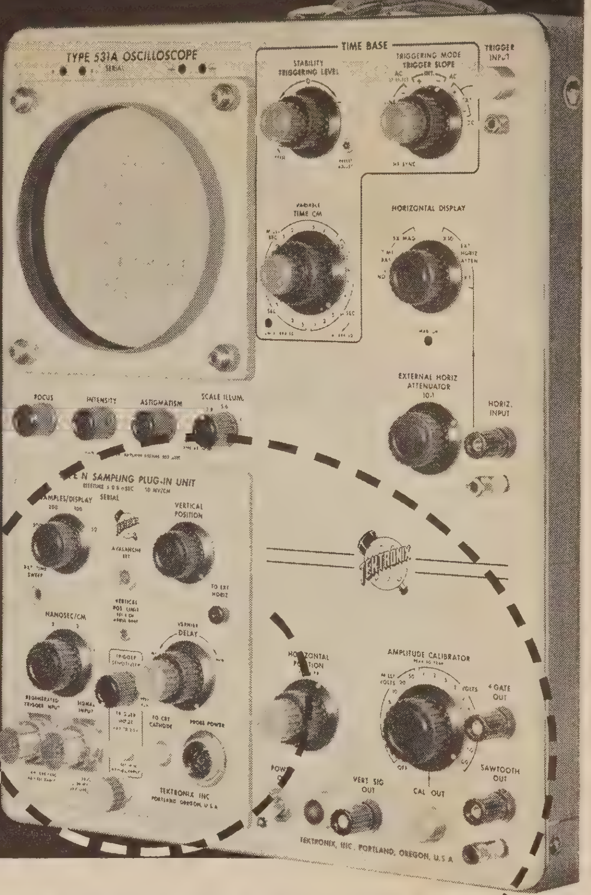
Tunnel Diode Switching Time Measurement

with Tektronix Type N Sampling Plug-In Unit



A convenient low-cost method of testing tunnel (Esaki) diodes with nanosecond switching speeds is shown above. A Tektronix Plug-In Oscilloscope provides both the current ramp source for the tunnel diode and the pretrigger for the Type N Unit. The N Unit is set up in the usual way — however, the oscilloscope main sweep generator is allowed to free run at 1 μsec/cm. The + GATE OUT not only triggers the N Unit but also provides a delayed current ramp with a low rate of change—which allows the tunnel diode to switch at essentially its own rate.





NEW PULSE-SAMPLING UNIT

for all Tektronix Plug-In Oscilloscopes

The new Type N Unit converts your Tektronix Plug-In Oscilloscope to a Pulse-Sampling Oscilloscope with a risetime of 0.6 nanoseconds. Applications in which the signal source can furnish a "pretrigger", such as that shown above, require no additional equipment.

For a completely versatile Pulse-Sampling System, Tektronix also manufactures a Pulse Generator and Trigger Takeoff, a 60-nsec Delay Line, a Pretrigger Pulse Generator, and several useful accessories. Please call your Tektronix Field Engineer for complete details and, if desired, a demonstration of the Type N Unit or the complete System.

Characteristics

0.6 nsec risetime (approximately 600 mc).

10 mv/cm sensitivity. (2 mv or less amplitude noise.)

1, 2, 5, and 10 nsec/cm equivalent sweep times (20 to 50 psec time noise).

50-ohm input impedance.

50, 100, 200, and 500 samples per display.

Sampling rate — 50 c to 100 kc.

±120 mv minimum linear range (safe overload 4 v).

Trigger input requirement: +0.5 v, 1 nsec duration, 40 nsec in advance of signal. Recovery time is 10 μsec. Counts down from 50 mc.

PRICE.........................**$600**
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Space Electronics—a new and rapidly expanding dimension in creative electronics—offers an environment to senior engineers and scientists which embodies those challenges and opportunities vital to individual growth. Young, but possessing a wealth of experience in missile electronics that is unsurpassed by any comparable firm, Space Electronics already has made significant and practical contributions to our nation's missile and space program.

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Positions Open

The following positions of interest to IRE members have been reported as open. Apply in writing, addressing reply to company mentioned or to Box No. ....

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TEACHING POSITION

Expanding, recently organized dept. with a modern science-oriented curriculum, seeks a well-qualified person who is interested primarily in teaching. Advanced degree required. This is an unusually attractive position for the right individual. 12 month salary assured, if desired for approximately 10½ months service. Possible to have every other summer off while earning full salary. Salary range is approximately $6,000 to $8,000. Private, medium-sized university in midwest. Send complete resume to Box 2011.

ENGINEER

Electronics Research and Development Lab. needs man with experience in transistor-circuit development. Position carries opportunity to study for advanced degrees in Physics or Engineering. Salary consistent with training and experience. Applicants will be required to have BS. degree or better in Physics or Engineering to qualify. For more details write Research Foundation, Oklahoma State University, Stillwater, Okla., or call R. F. Buck, FRontier 2-6211, Ext. 579, after 5 P.M. or holidays call FRontier 2-8480.

ELECTRICAL ENGINEERS

University appointments Electrical Engineering. Three openings including the Chair in Electrical Engineering in new Faculty of Applied Science with opportunity for advancement and research. Attractive salary schedule. New building under construction. Ph.D. or Master's degree desirable. Apply to F. A. DeMarco, Principal, Essex College, Windsor, Ontario.

TEACHING POSITION

Expansion of graduate work in E.E. at Syracuse University has created several openings at the Assistant and Associate Professorial ranks. Except in very unusual circumstances, applicants should have a Doctorate in E.E. or a closely allied field. Opportunities exist for combination of teaching and research during the academic year, and for summer employment on research. Teaching is primarily at the graduate level. Salary depends on experience, but in most cases the yearly salary (for 11 months work) is reasonably competitive with industry. Write to Dr. W. R. LePage, Chairman, Dept. of E.E., Syracuse University, Syracuse 10, New York.

ASSOCIATE OR ASSISTANT PROFESSOR

Expert in field of semiconductors. Ph.D. is minimum requirement, applicant must have some teaching experience. Academic rank and salary dependent on demonstrated ability and over-all experience. The man in this position will divide his time between teaching and research. Appointment begins Sept. 1960. Write, including resume to W. R. Beam, Head, E.E. Dept., Rensselaer Polytechnic Institute, Troy, N. Y.

(Continued on page 138A)

Professional placement report
for Electronics Engineers

How the continuous need to improve the nation's space surveillance capabilities opens avenues for new engineering careers

The continuous need we are talking about at General Electric refers to the fact that future-generation missiles, satellites and deep space probes will require refined or entirely new detection techniques, including many that have not yet been conceived.

For example, it is anticipated that for every technical discipline now utilized in the detection field, at least one more must be found to apply within the next 10-year period.

With this in mind, General Electric is increasing its electronics engineering staff now working on advanced missile, satellite and deep-space-probe detection systems. Keeping pace with this expansion, the Company added a new building last year, and another will be ready for occupancy in a few months.

First clues to this trend were obvious in General Electric's well known "Golfball Study," published five years ago. This study compared the problem of missile detection to that of locating a golfball 200 miles away, using the most advanced techniques available in 1954. The problem no longer has such proportions, thanks to the creative imagination of dedicated General Electric engineering, scientific, and technical personnel responsible for designing and developing the unique surveillance sub-system of the Ballistic Missiles Early Warning System (BMEWS) which is receiving headline attention today.

Find out more about these creative and self-expressive opportunities now open to qualified personnel in one of the most vital technologies of the space age.

GENERAL ELECTRIC

Immediate openings for qualified electronics engineers

RADAR EQUIPMENT SYSTEMS SPECIALISTS capable of conceiving and directing the design of long-range radar systems. Desirable experience includes 3 to 10 years in at least one of the following: radar systems design, antenna systems, RF components, transmitters, radar receiver systems or radar data processing systems. Salary structure is fully equal to the professional requirements of the job.

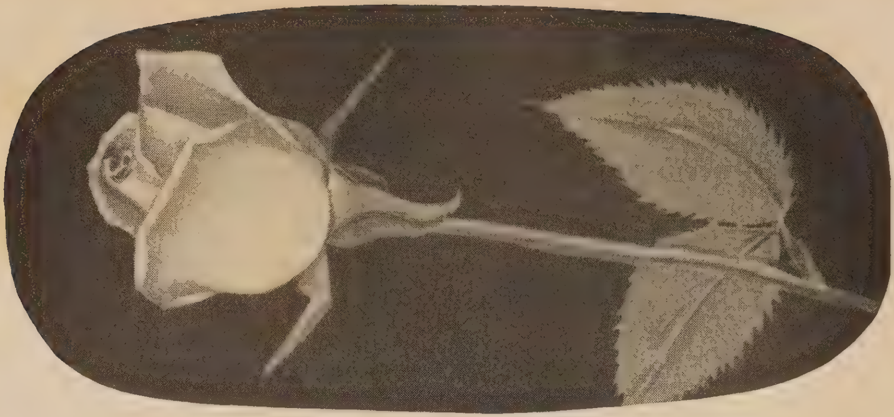
ADVANCED SYSTEMS ENGINEERS capable of defining future defense and space detection problems including deep space-probe tracking. Also the ability to conceive and establish the feasibility of optimum systems solutions to these problems—making use of the most advanced techniques and understandings. Also required is an ability to recognize the need for, and coordinate the development of, new techniques and the exploration of new phenomena. Experience requirements include a Bachelor degree plus a combination of advanced training and several years' experience in both the theoretical and practical aspects of detection systems engineering. A desire to work in the conceptual phase of systems design with the analytical ability required to evaluate and demonstrate the effectiveness of the proposed systems is essential.

FIELD OPERATIONS ENGINEERS for systems management teams to be deployed at complex radar systems installations of the BMEWS type. Systems-oriented Electronics Engineers are needed who have the ability to assume responsibility for installation, checkout, and integration of major radar systems. Background in high-powered Klystron transmitters, low-noise receivers and digital data processing equipment is desirable. A Bachelor degree is required.

ADDRESS YOUR INQUIRY IN CONFIDENCE TO:
MR. JOSEPH WOOL, PROFESSIONAL PLACEMENT, DEPT. T-4
MISSILE DETECTION SYSTEMS SECTION
HEAVY MILITARY ELECTRONICS DEPARTMENT
GENERAL ELECTRIC COMPANY
COURT STREET, SYRACUSE, NEW YORK

Qualified applicants will be invited to visit us in Syracuse at Company expense. Relocation assistance will be provided. 177-25

GENERAL ELECTRIC



At Bendix York, we have a number of immediate openings for Electronic Engineers and Physicists.

There are many worthwhile advantages awaiting the Professional Engineer who chooses to advance his career with us at Bendix York.

A white rose . . .

The white rose is a symbol at Bendix York . . . a symbol with two meanings. Both of vital importance to *your* future.

First, the white rose is the official flower of York, Pennsylvania. It is a symbol of the good life in our dynamic community, located in the heart of the scenic Pennsylvania Dutch region. It is a wholesome, happy area with excellent schools, delightful recreational opportunities and many cultural advantages. Here—away from high-pressure, high-cost, big-city living—you will enjoy the fuller, more rewarding life that you want for yourself and for your family.

Second, the white rose is a symbol of perfection . . . the perfection for which we strive at Bendix York—perfection in the engineering and scientific pioneering and development in missile electronics that is our principal objective.

We offer a small Division's assurance of individual recognition and advancement, and yet you have the security and employee benefits of a large corporation.

We would like to have the opportunity to tell you more about Bendix York. We invite you to contact us—by dropping us a post card, by giving us a call or, if you will, by sending us a brief resume. Address Professional Employment: Dept. P

Bendix
AVIATION CORPORATION

YORK DIVISION

York, Pennsylvania
Phone: York 47-1951

ENGINEERS

NOW—CHOOSE YOUR ASSIGNMENT AND LOCATION THROUGH OUR NATION-WIDE PLACEMENT SERVICE

SALARIES $7,500 TO $18,000

We can offer you a large selection of diversified positions with America's foremost electronic organizations. Some positions for non-citizens.

The following are just a few of a large number of desirable opportunities.

SR. ENGR.—DIGITAL COMPUTERS— Exp. required in systems, logical design, packaging, system integration or pulse circuitry. To $15,000

FLIGHT TEST EVALUATION—Sr. Opp in Ground & Flight Test on data links, precision transducers, telemetering equipment, power supplies, circuit monitors and impedance matching units. To $15,000

RF ANTENNA—Proj. Engr. $15,000

INFRA RED—Proj. Engr. $15,000

CIRCUIT DESIGNERS — 2-5 years Transistor experience. $11,000

ADVANCED SYSTEM DEVELOPMENT —Supervisory position in digital computer, fire control or missile guidance development. To $17,000

PHYSICIST Phd.—Nuclear experience pertaining to radiation from propulsion units—unusual opportunity. To $18,000

PROJECT LEADER—Antenna Pedestals. $13,000

SR. ENGINEER—DEVELOP Airborne & spaceborne communications systems. $15,000

Just tell us what you would like to do and where you would like to locate, and we will handle everything for you without cost or obligation.

LOCATION DESIRED

☐ New England
☐ Northern East Coast
☐ Southern East Coast
☐ Midwest
☐ Southwest
☐ West Coast

POSITION DESIRED

☐ Systems
☐ Radar
☐ Transistors
☐ Tubes
☐ TV Receivers
☐ Microwave
☐ Anal. Computers
☐ Dig. Computers
☐ Antenna
☐ Servo-Mechanisms
☐ Navigation
☐ Counter Measures
☐ Telemetering
☐ Nucleonics
☐ Ind'l. Instruments
☐ Components
☐ Circuit Design

WHAT SATISFIED ENGINEERS SAY:

Dear Mr. Brisk:
This is to advise you I have accepted employment with ———— Company as a project leader at $15,000.
Your service has been a real help to me, for I am sure I could not have found this unusual opening by myself.
Thank you.
H.M.P.

Dear Mr. Brisk:
I have today advised ———— Company that I would be pleased to accept their offer. I start August 1st as a senior engineer at $13,000.
The opportunity is one of the most outstanding I have seen.
J.S.E.

A National Electronic Placement Service Established in 1937.
You are assured of prompt and completely confidential service by forwarding three resumes to* HARRY L. BRISK, *(Member IRE)

APS **Accredited Personnel Service**

Employment Counselors Since 1937
Department A
12 South 12th St., Philadelphia 7, Penna. WAlnut 2-4460

Positions Open

(Continued from page 134A)

EDITOR

Scientific book publisher needs radio engineer to plan and develop new books. Publishing experience desirable. Write in detail. State salary. Box 2012.

ENGINEERS

Major firm seeking (1) Section leader, Electromechanical design, (2) Section leader, testing and reliability, knowledge of Military acceptance testing, (3) Manufacturing engineers, knowledge of standards, process and tool engineering for electromechanical display equipment. Top future positions. Benefit programs. Salaries $8,000–$15,000. Contact Mr. W. Hart, Witty-Polon Management Consultants, 176 East 75 St., New York 21, N. Y. Telephone: Lehigh 5-4222.

INSTRUCTOR AND ASSISTANT PROFESSOR

For those interested in teaching fundamental electrical & electronic subjects. Opening for fall semester beginning Sept. 1960. Salary depends on qualifications. New building and equipment. Opportunity for advancement and further study. 9 month academic year. Part time evening session work available. Health Insurance and Pension Plan. Send complete resume to Prof. I. L. Kosow, Dept. Head. Electrical Technology, Staten Island Community College, 50 Bay St., Staten Island 1, N. Y.

ELECTRICAL ENGINEERING PROFESSORS

Fast growing Engineering School on west coast needs 3 electronic-electrical engineers able to teach circuits and electronics, with a specialty in communications, industrial electronics or computers. MS. degree plus industrial experience is the minimum requirement; a Ph.D. is desirable. Salary and rank will depend on experience. The dept. has just moved into a new building and needs aggressive men who wish to develop curricula and labs. Apply L. Cromwell, Head, E.E. Dept., Los Angeles State College, 5151 State College Dr., Los Angeles 32, Calif.

PROFESSOR

Assistant and/or Associate Professor of E. E. with interest and experience in one of the following areas: electromagnetic theory, information theory, digital computer logic and numerical methods, solid state. Ph.D. required, Combination of research, graduate and undergraduate teaching. Address inquiries to Dr. C. Polk, Head Dept. of E.E., University of Rhode Island, Kingston, Rhode Island.

PROJECT ENGINEER

Project Engineer to supervise complete projects in design and development of automatically sequencing, self checking test equipment used to evaluate complex airborne guidance systems and components, as well as industrial process instrumentation. E.E. plus 5–7 years experience. Kearfott Div.—General Precision, Inc. Att: P. Kull, 1500 Main Ave., Clifton, New Jersey.

SENIOR ELECTRICAL ENGINEER

E.E. degree and 8-10 years experience including experience in electronics. Interesting work in conjunction with a nuclear physics research program. Benefits include a reduced tuition rate for the employee and free tuition for children of employees with 5 or more years of service. If interested, send complete resume, in-

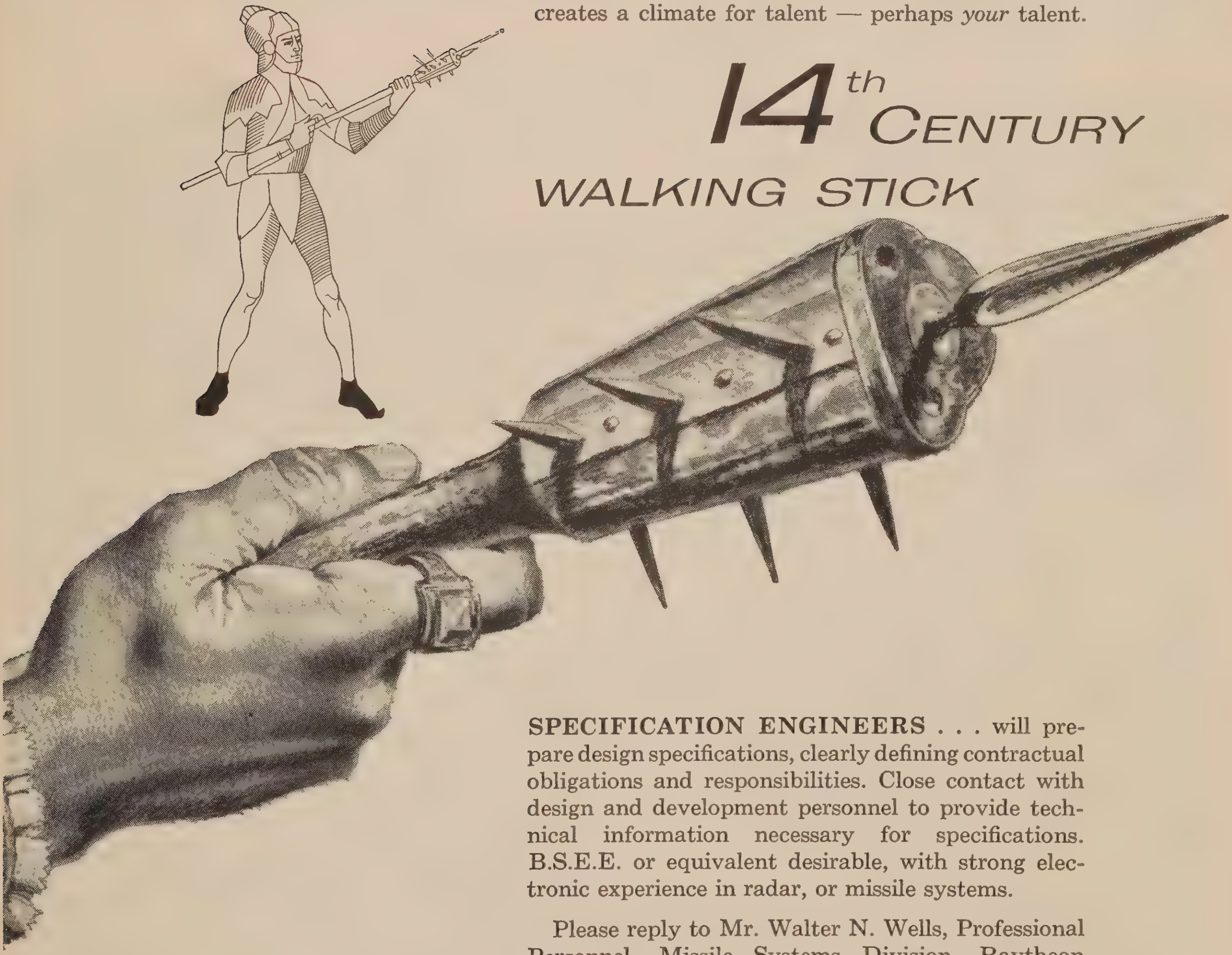
(Continued on page 143A)

This "bazooka" type cannon of 1395 fired lead, lapidary and finned missiles. Their main disadvantage — practically impossible to aim or guide to its target. The missile was named after Henry VIII because he was considered a connoisseur of walking sticks which were often used to conceal weapons.

Today, as a vital part of one of the world's largest electronics companies, Raytheon's Missile Systems Division is making significant contributions to the art of missilry. The exciting new Pin Cushion Project for selective missile identification, the constantly advancing Navy's air-to-air SPARROW III and Army's HAWK are examples of their outstanding creative work.

We are seeking highly creative people to maintain Raytheon's leadership in this challenging field. For these people, Raytheon's Missile Systems Division creates a climate for talent — perhaps *your* talent.

14th CENTURY WALKING STICK



SPECIFICATION ENGINEERS . . . will prepare design specifications, clearly defining contractual obligations and responsibilities. Close contact with design and development personnel to provide technical information necessary for specifications. B.S.E.E. or equivalent desirable, with strong electronic experience in radar, or missile systems.

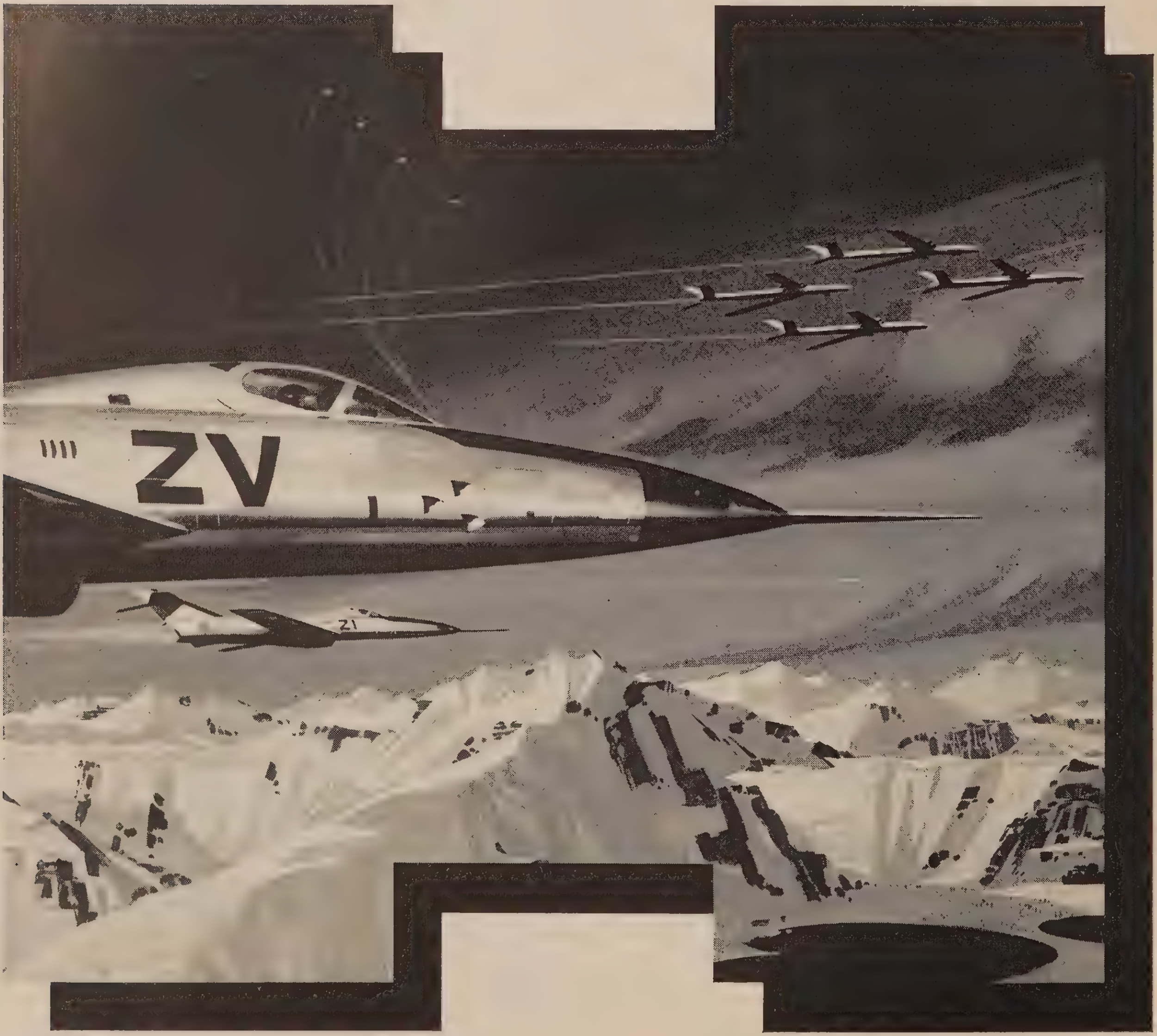
Please reply to Mr. Walter N. Wells, Professional Personnel, Missile Systems Division, Raytheon Company, 520 Winter Street, Waltham, Mass.

19WSE

RAYTHEON *MISSILE SYSTEMS DIVISION*

...creates a climate for talent.

How will this picture look



in ten seconds?

In ten seconds these aircraft, flying at jet speeds, will create an entirely new tactical picture. How do you keep track of hundreds of them at the same time?

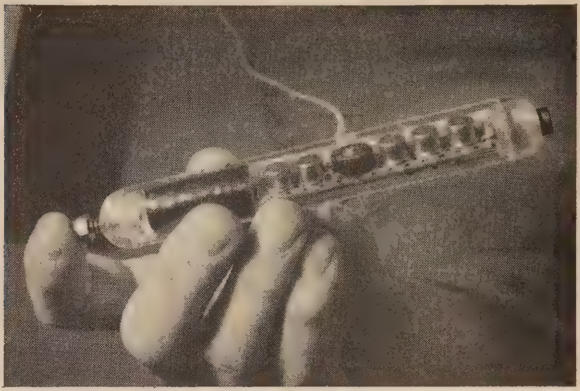
Hughes Fullerton engineers have solved this problem with a unique and highly advanced digital computer. This computer simultaneously tracks large numbers of aircraft and provides three-dimensional coordinate and velocity information on them.

These Fullerton engineers have designed the computer to provide extrapolated position data to the observer several times per second. In addition, it will measure the position and report velocity characteristics changes every few seconds for each of a large number of targets.

The computer utilizes advanced semiconductor circuitry throughout. The out-puts to the displays are made through high-speed digital to analog converters capable of providing an accuracy of one part in ten thousand — and within 10 x 10^{-6} seconds.

This giant transmitting antenna *creates the beam for experimental antenna pattern measurements — part of the Hughes microwave research and development programs.*

Housed in the tip *of this Hughes survey meter is the smallest, fastest, most accurate radiation detector ever devised — just one example of Hughes' activities in the expanding field of nuclear electronics.*



Utilizing the latest techniques in packaging and subminiaturization, Hughes Fullerton Engineers have designed this unit as a mobile system which will withstand rigorous field use.

Other Hughes activities provide similarly stimulating outlets for creative engineers. Constantly moving forward into new areas, Hughes projects include: hydrofoil systems, anti-submarine warfare systems, miniaturized communications systems, new solid state electronics devices, nuclear electronics systems and unique navigational systems — just to name a few.

The commercial activities of Hughes have many interesting projects for engineers in the research, development and manufacture of semiconductors, microwave components, storage tubes, radiation detectors, radiation handling equipment and microwave tubes.

Whatever your field of interest, you'll find Hughes' diversity of advanced projects gives you widest possible latitude for professional and personal growth.

Newly instituted programs at Hughes have created immediate openings for engineers experienced in the following areas:

- Electroluminescence
- Infra-red
- Solid State Physics
- Digital Computers
- Reliability & Quality Assurance
- Systems Design & Analysis
- Equipment Engineering
- Microwave & Storage Tubes
- Communications Systems
- Inertial Guidance
- Field Engineering
- Circuit Design & Evaluation

Write in confidence to Mr. M. W. Welds
Hughes General Offices, Bldg. 6-E5, Culver City, Calif.

Creating a new world with ELECTRONICS

HUGHES

HUGHES AIRCRAFT COMPANY
Culver City, El Segundo, Fullerton, Newport Beach,
Malibu, Oceanside and Los Angeles, California;
Tucson. Arizona.

PRELIMINARY DEVELOPMENT

SENIOR ENGINEERING SPECIALISTS

Honeywell Aero Preliminary Development Staff has several openings for technically qualified and mature engineers with significant military system development experience. Each man will provide guidance and support in his specialty to Honeywell design projects for the best use of advanced techniques in development of new airborne systems. These staff positions offer scope for original personal contributions and will require active participation in the formulation and execution of Division engineering programs. Among the openings are:

WEAPON DELIVERY AND CONTROL SYSTEMS SPECIALIST

Background of system and computer development for bombing, fire control, or navigation. Firsthand experience with system analysis, tie-in requirements, analog and digital computers, operations analysis, and weapon effectiveness evaluation.

DETECTION SYSTEMS SPECIALIST

Primary background of airborne radar development in one or more areas such as AMTI, Doppler, pulse Doppler, automatic tracking, and countermeasures. Experience in infrared or communications will be valuable. Experience should include system analysis, design requirements, equipment development, and performance evaluation.

ELECTRONIC CIRCUIT AND PACKAGING SPECIALIST

Background of circuit design for advanced control and computation equipment. Should be familiar with dc, low frequency, pulse and rf techniques. Must be able to establish sound analytical basis for circuit design to specific levels of reliability and performance. Must be experienced with solid state devices and prepared to contribute to Aero Division work on microcircuit techniques.

To discuss openings for these and other specialties, write or phone Mr. J. R. Rogers, Chief Engineer, Preliminary Development Staff, Dept. 610E, Aeronautical Division, 1433 Stinson Blvd., Minneapolis 13, Minn.

Honeywell

H Military Products Group

To explore professional opportunities in other Honeywell operations coast to coast, send your application in confidence to H. K. Eckstrom, Honeywell, Minneapolis 8, Minnesota.

Electronic Engineers

EXCELLENT POSITIONS ARE OPEN IN

PACIFIC MISSILE RANGE PROJECTS

Career civil service positions with the Navy are now open for qualified electronic engineering applicants. Salaries range from $8810 to $10,130, plus excellent additional benefits and established promotional and advancement opportunities.

Work involves project management, design, development and installation of vast-scale electronic instrumentation systems for the Pacific Missile Range.

Areas of employment are the Pacific Missile Range, Point Mugu, Calif.; the Naval Missile Facility, Point Arguello, Lompoc, Calif.; and the Office of Resident Industrial Manager, San Diego, Calif. Inquiries should be directed to the Industrial Relations Office, Dept. A.

NRF

U. S. NAVAL REPAIR FACILITY

San Diego 36, California

STANFORD RESEARCH INSTITUTE

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ELECTRONIC ENGINEERS

PHYSICISTS

MATHEMATICIANS

to participate in research for:

- PROPAGATION
- CONTROL SYSTEMS
- MICROWAVE COMPONENTS
- SYSTEMS ANALYSIS IN
  - Missiles
  - Space Systems
  - Communications
- ANTENNAS
- COMMUNICATIONS THEORY
- MATHEMATICAL RESEARCH
- INFORMATION THEORY
- COMPUTER MAGNETIC DEVICES

SRI

If you are interested in research as a way of life, SRI offers you varied and professionally stimulating research in an atmosphere of quiet dignity.

You can share rewarding professional association, excellent research facilities and responsible assignments with the delightful bonus of living and working in California's San Francisco Bay Area.

Projects are open to qualified personnel on the MS and PhD level who have 3 years or more experience in Electronic Engineering or Applied Physics.

Advanced study opportunities
Industrial level salaries.

Write to . . .

PROFESSIONAL EMPLOYMENT MANAGER
STANFORD RESEARCH INSTITUTE
MENLO PARK, CALIFORNIA

Positions Open

(Continued from page 138A)

cluding salary expectations to J. R. Whitley, Employment Supervisor, University of Rochester, 260 Crittenden Blvd., Rochester 20, N.Y.

MEDICAL ELECTRONICS

Biophysical Electronics, Inc. devotes its efforts to the design and manufacture of instruments assisting the physician, psychologist, and research scientist to meet the challenge of preserving and extending life. Positions are open for: Senior Transistor Circuit Designer, Sales and Office Manager and experienced Electronic Technician. Submit resume, availability and salary requirements in first letter to Biophysical Electronics, Inc., New Hope, Pa.

ELECTRONICS ENGINEER OR PHYSICIST

High qualifications and varied experience, particularly in control, rf or nuclear electronics. Appointment as Assistant Professor at $7,000-$8,900 or as Associate Professor at $9,000-$11,700, or to non-academic position at equivalent salaries. To supervise construction of a spiral-ridge cyclotron to produce 50 Mev protons. Apply to Dr. B. G. Whitmore, Physics Dept., University of Manitoba, Winnipeg 9, Manitoba, Canada.

ENGINEER

To assist in construction of new cyclotron installation. Permanent position. Experience in building and maintaining scientific apparatus essential. Specific experience with cyclotrons desirable. Salary dependent on qualifications and experience. Apply to Dr. B. G. Whitmore, Physics Dept., University of Manitoba, Winnipeg 9, Manitoba, Canada.

(Continued on page 144A)

SCIENTISTS
ENGINEERS

CALIFORNIA

offers you and your Family

- A world center of the electronic industry for CAREER ADVANCEMENT
- The High Sierra and the Pacific Ocean for RECREATION
- Some of the nation's finest public schools for your CHILDREN
- World Famous Universities for ADVANCED STUDY
- MAJOR CULTURAL CENTERS

while living in such places as
Exciting San Francisco
Fabulous Southern California
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companies pay interview, relocation and agency expenses

submit resume in confidence to:

PROFESSIONAL & TECHNICAL RECRUITING ASSOCIATES
(a Division of the
Permanent Employment Agency)
825 San Antonio Rd.
Palo Alto, Calif.

TAKE A GIANT STEP

...into your future and seek out the professional opportunities awaiting creative engineers and scientists at Martin-Denver... For here exists the most challenging problems in space and human engineering. Join with us and communicate with N. M. Pagan, Director of Technical and Scientific Staffing (Dept. DD-10), The Martin Company, P. O. Box 179, Denver 1, Colo.

MARTIN
DENVER

Professional Opportunities Are Available For

Electrical Engineers

with interest and experience
in the following fields:

- Design and Development of:
  Industrial Electronics and Power Controls and Instrumentation Electronics
- Operation & Maintenance of Nuclear Devices

For information please write to:
Personnel Manager

Brookhaven
National
Laboratory

UPTON, LONG ISLAND, N. Y.

LINCOLN LABORATORY

invites inquiries from persons with superior qualifications.

SOLID STATE Physics, Chemistry, and Metallurgy

RADIO PHYSICS and ASTRONOMY

NEW RADAR TECHNIQUES

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  Techniques
  Psychology
  Theory

INFORMATION PROCESSING

SYSTEMS:
  Space Surveillance
  ICBM Detection and Tracking
  Strategic Communications
  Integrated Data Networks

SYSTEM ANALYSIS

Research and Development
LINCOLN LABORATORY
Massachusetts Institute of Technology
BOX 16 · LEXINGTON 73, MASSACHUSETTS

Positions Open

(Continued from page 143A)

TEACHING-RESEARCH, ELECTRICAL ENGINEERS

Expanding university program provides unusual opportunities for positions combining teaching and research. Rank and salary open. Teaching in all E.E. fields. Research primarily in microwave electronics. Apply: Dean E. C. Easton, Rutgers University, New Brunswick, New Jersey.

TEACHING AND RESEARCH

Attractive opening for Electrical Engineer with Ph.D. to help develop graduate program, supervise graduate research and do some teaching. Encouragement given to private research and consultation. Good salary and faculty ranking will be offered to exceptional individual. Position available Sept. 1960 or sooner. Write, Dean, School of Engineering, Vanderbilt University, Nashville 5, Tenn.

ELECTRONIC ENGINEERS

Positions open to Electronic Engineers teaching lecture and laboratory courses in a rapidly growing 4 year college. A background of servomechanisms, circuit analysis, microwaves, and/or transistors is desired. Applications desired from both academic and industrial personnel. Write, Harold P. Skamser, Dean of Engineering, Calif. State Polytechnic College, Kellog-Voorhis Campus, Pomona, Calif.

TEACHER IN ELECTRICAL ENGINEERING

Teacher in E.E. beginning Sept. 1960. One qualified and interested in teaching fundamental undergraduate courses plus one graduate course. Ph.D. or MS. required with salary and rank dependent on qualifications. City location with many industrial contacts. Apply Dept. of E.E., Saint Louis University, St. Louis 8, Missouri.

STAFF ENGINEER

Research engineering position for creative person to form nucleus of a new section in the Electro-physical Labs. Will propose and evaluate new electronic component, circuit and systems concepts. Minimum experience and educational background would be 5 years with at least an MS. in E.E. or Physics. A Ph.D. degree would be preferred with strong interests in electronics, theoretical physics or mathematics. Forward resumes to Mr. R. D. Williams, Employment Mgr., P. R. Mallory & Co. Inc. 3029 E. Washington St., Indianapolis, Ind.

ANALYST

Research and consulting in fields such as transportation, logistics, equipment investment, inventory control, marketing, operations research, data processing. Educational background in economics, transportation, mathematics, statistics, engineering. United Research, Inc., 808 Memorial Dr., Cambridge, Mass. Mrs. Paulsen, Personnel Director.

TEACHING POSITIONS

The E.E. Dept. of The City College of New York has several positions available on the teaching staff beginning September 1960. Rank and salary commensurate with qualifications and experience. Opportunity for graduate study. Applicants must be present resident of the U.S. Address inquiry to Prof. H. Taub. Dept. of E.E., The City College, Convent Ave., & 139th St., New York 31, N.Y.

(Continued on page 146A)

SAN JOSE
Current Career Opportunities

In Commercial Products R&D

ELECTRONIC ENGINEERS
PHYSICISTS

experienced in Industrial Electronics and Automation

Creative top level engineers and physicists are needed now to work on advanced assignments in the design of optimum systems using electronic and mechanical components.

FMC Central Engineering's current expansion into automatic measurement and control fields offers permanent career opportunities for technical accomplishment on important company-sponsored, long-range programs. Systems engineers, circuit designers and specialists needed to staff new million dollar laboratories.

With corporate headquarters in San Jose, California, FMC is highly diversifed in both machinery and chemicals, with 15 divisions operating throughout the U. S. and overseas.

BS required and advanced degrees desirable for these responsible positions. Experienced applicants or recent graduates should send complete resume:

Contact E. M. Card, Jr., or C. F. Duvall at FMC Central Engineering, P.O. Box 760, San Jose, Calif. Phone: CYpress 4-8124.

Putting Ideas to Work

Central Engineering Laboratories

FOOD MACHINERY AND CHEMICAL CORPORATION

An Invitation To Join ORO...Pioneer In Operations Research

Operations Research is a young science, earning recognition rapidly as a significant aid to decision-making. It employs the services of mathematicians, physicists, economists, engineers, political scientists, psychologists, and others working on teams to synthesize all phases of a problem.

At ORO, a civilian and non-governmental organization, you will become one of a team assigned to vital military problems in the area of tactics, strategy, logistics, weapons systems analysis and communications.

No other Operations Research organization has the broad experience of ORO. Founded in 1948 by Dr. Ellis A. Johnson, pioneer of U. S. Opsearch, ORO's research findings have influenced decision-making on the highest military levels.

ORO's professional atmosphere encourages those with initiative and imagination to broaden their scientific capabilities. For example, staff members are taught to "program" their own material for the Univac computer so that they can use its services at any time they so desire.

ORO starting salaries are competitive with those of industry and other private research organizations. Promotions are based solely on merit. The "fringe" benefits offered are ahead of those given by many companies.

The cultural and historical features which attract visitors to Washington, D. C. are but a short drive from the pleasant Bethesda suburb in which ORO is located. Attractive homes and apartments are within walking distance and readily available in all price ranges. Schools are excellent.

For further information write:
Professional Appointments

OPERATIONS RESEARCH OFFICE
ORO **The Johns Hopkins University**
6935 ARLINGTON ROAD
BETHESDA 14, MARYLAND

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Chicago, Ill., and Menlo Park, Calif.

The continuing expansion program at Zenith has created new opportunities for engineers with experience in the above fields.

The fast-wave **electron-beam parametric amplifier,** conceived at Zenith, has opened up challenging new fields for research and development activity from UHF to SHF bands. Broad company interests in the microwave-tube area provide fertile atmosphere for original ideas and individual initiative.

An expanding research program in new fields centered around **compound semiconductors** provides opportunities for individuals with backgrounds in the solid-state art. Development of special devices for highly specific purposes, in collaboration with applications engineers, represents another area of active interest in the semiconductor field.

Positions are now available in the Research Department at Chicago; some openings are available in the San Francisco Bay Area. Congenial small-group atmosphere prevails, with all the advantages of a large, progressive company.

Interested applicants please contact:

DR. ALEXANDER ELLETT
Zenith Radio Corporation
6001 Dickens Avenue
Chicago 39, Illinois

BErkshire 7-7500

PROFESSORS

Electrical Engineering Faculty in new and rapidly expanding university has openings at senior levels. Duties include graduate teaching and research. Immediate opening for professor interested in developing courses and participating in research in logic, switching and computery. Ph.D. essential. Salary up to $13,000. Apply Chairman, Electrical Engineering Department, University of Waterloo, Waterloo, Ontario.

Positions Open

(Continued from page 144A)

ENGINEERS

The University of Denver's Research Institute is seeking graduate electronic engineers in the areas of circuit design and development, system design, and field engineering. Openings exist at all levels from engineers with advanced degrees and several years experience to recent graduates. Opportunities are available for advanced study or part-time teaching in the College of Engineering. Address inquiries to C. A. Hedberg, Head, Electronics Div., Denver Research Institute, University of Denver, Denver 10, Colo.

ELECTRONICS PATENT ATTORNEY OR AGENT

Eastern U.S. company engaged in a broad line of developments in the electronics field has an opening for a patent attorney or agent. Applicant should have excellent comprehension of electronics, together with some experience in patent prosecution. Salary and position will be dependent on background and indicated ability. In reply please supply information as to education, experience and salary expected. Box 2017.

PHYSICIST OR ELECTRICAL ENGINEER

Research on interaction between EM waves and structures or particles. An opportunity to do independent undirected research in the field of plasma or electron physics with excellent technical support and recognized colleagues. An experienced research with original ideas is desired. Salary $10,000 plus, depending on training and experience level. Write Box 2018.

ANALOG COMPUTER ENGINEER

The Standard Oil Co. (Ohio) has an immediate opening for an Analog Computer Engineer. A minimum of a B.S. in E.E. or Physics and 2-5 years analog experience is required. Applications are in the field of simulation and study of chemical and refining processes and process control systems. Salary commensurate with experience. Apply Mr. C. A. Bruggers, The Standard Oil Co. (Ohio), 1737 Midland Bldg., Cleveland, Ohio.

MEDICAL ENGINEERING

Electronics Engineer or Physicist. Permanent position in Dept. of Surgical Research of a large eastern university, involves design of new instruments, supervision of maintenance of equipment, and consulting with physicians. Salary range open. Send complete resume to Box 2019.

ENGINEER

Engineer to conduct a research and development program on instrumentation for data accumulation, reduction, and processing in geology, water resources investigations, photogrammetry, and allied fields including the development of new equipment and techniques for sensing, digitizing, logging, transmitting, storing, and processing of mass data. Contact Personnel Officer, U.S. GEOLOGICAL SURVEY, Washington 25, D.C.

ELECTRONIC ENGINEER

Electronic Engineer to teach lecture and laboratory courses. Up-to-date knowledge of the field required. Working and living conditions excellent; salary and opportunity very attractive. Write to Dean of Engineering, California State Polytechnic College, San Luis Obispo, Calif.

(Continued on page 152A)

active programs in 19 critical electronic areas

Offer You Opportunities
To Participate In Significant
Advances at
STROMBERG-CARLSON
Division of General Dynamics

Top-calibre research and development teams at Stromberg-Carlson are tackling the prime problem areas in electronics affecting commercial communities and national defense. Programs and R & D staffs are expanding, backed by the vast resources of General Dynamics and the Stromberg-Carlson engineer-oriented management.

Every senior engineer and scientist who feels he can contribute to the expansion of man's capabilities in any of the following areas is invited to contact us.

We are particularly interested in people with advanced degrees in Physics, Electrical Engineering or Mathematics and experience in one or more of the areas listed. Please send resume in confidence to Technical Personnel Department.

ENGINEERING AND ADVANCED DEVELOPMENT

Advanced ICBM Communications
Electronic Switching
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High-Speed Digital Data Communications
Electronic Reconnaissance Systems
Single Sideband Communications
Synchronous Data Transmission
Advanced ASW Techniques
Machine Tool Automation
Radio Data Links • Tacan Equipment
High Intensity Sound Generators
Advanced Air Acoustics
Shaped Beam Display Systems
High-Speed Automatic Missile Check-Out Equipment
Super-Speed Read-Out and Printing Equipment

RESEARCH

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Thin Photoconductor Films
Propagation and Coding • Speech Analysis
Bandwidth Compression • Hydro-Acoustic Transducers
Defect Solid State Physics
Parametric Devices • Molecular Electronics
Tunnel Diode Logic • Scatter Propagation Analysis

STROMBERG-CARLSON
A DIVISION OF **GENERAL DYNAMICS**

1476 N. Goodman St., Rochester 3, New York

CRYSTAL FILTERS

Within three years Hermes Electronics Co. has become the nation's leading producer of frequency selective devices utilizing piezoelectric crystal resonators. The growing demand for crystal filters and related devices has created a number of career opportunities for: Circuit Design Engineers, Crystal Physicists, and Network Theory Specialists.

Hermes Electronics Co. is a unique organization where responsibility and initiative are encouraged. Here you will also find the stimulation and environment of a young and growing company. Your association will be with staff members who are in the vanguard of many of today's rapidly expanding technical frontiers.

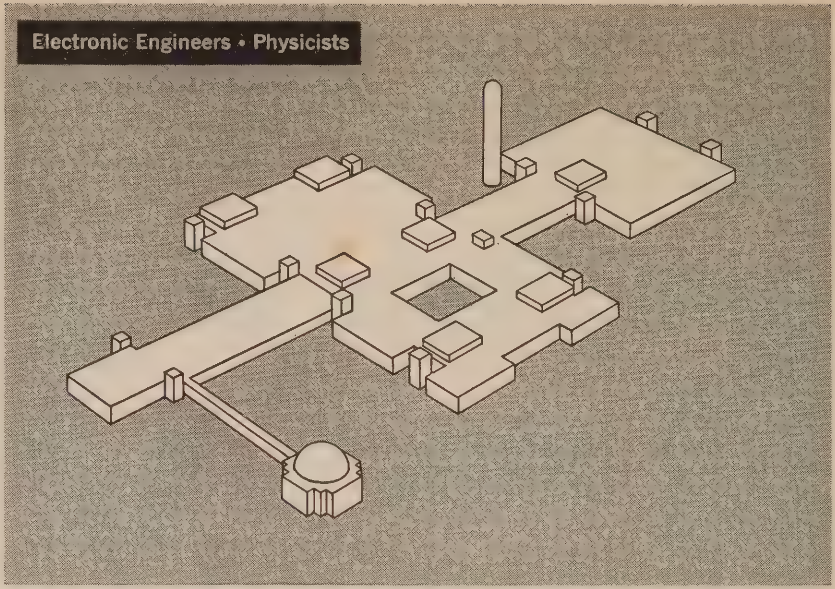
Salaries and other benefits are comparable to those of major research and development organizations. The company's location in Cambridge, Mass. affords unequaled cultural, living, and recreation facilities.

Liberal educational benefits are allowed for graduate study at leading universities in this area.

Interested scientists and engineers are invited to address inquiries to: Mr. E. E. Landefeld, Personnel Director.

Hermes
Electronics Co.
75 CAMBRIDGE PARKWAY
CAMBRIDGE 42, MASSACHUSETTS

Electronic Engineers • Physicists



COMMUNICATIONS PHYSICIST

Plan applied research in such areas as telemetry and radar detection as affected by plasma sheaths. Interpret space communication needs and problems. MS or PhD in EE or applied physics.

SYSTEMS ENGINEER COMMUNICATONS

EE or Physicist with 10 years' experience in systems design of airborne communications; to work on design of communication systems to meet requirements for future space vehicles.

ENGINEER-NAVIGATION AND GUIDANCE

To conduct analytical studies on inertial guidance and control for space vehicles. Should have background in closed-loop systems with 10 years of applicable experience and degree in EE or physics.

SYSTEMS ENGINEER NAVIGATION & CONTROL

EE with control systems background. Required are five years' experience in design of control and navigation systems, preferably in space vehicle systems.

ENGINEER ADVANCED ANTENNA & PROPAGATION STUDIES

To provide high level theoretical and experimental studies of antennas, propagation and target reflectors for all radio frequency bands, leading to new and improved concepts of equipment. BS, EE (advanced degree desirable). Six years' experience in above fields required.

ANALYSIS AND SYNTHESIS ENGINEER

Responsible for synthesis of new instrumentation and communication systems to meet missile and satellite requirements. Analytical knowledge in the field of instrumentation, communication and data processing with BS or MS EE essential.

INSTRUMENTATION SYSTEM TEST & EVALUATION ENGINEER

Coordinate tests on missile and satellite instrumentation systems. Requires experience in instrumentation and communication test and ground station equipment with BS,EE.

Other significant opportunities exist in the following areas:

Systems Engineering • Aerodynamics • Space Mechanics • Arming & Fuzing Systems • Airframe Structural Design • Materials Studies • Flight Test Analysis • Vibration Engineering • Producibility Engineering • Human Factors • Plasma Physics • Gas Dynamics • Applied Mathematics • Ground Support Equipment • Reliability Engineering • Project Engineering

For further information regarding opportunities here, write Mr. Thomas H. Sebring, Div. 53ME.
You will receive an answer within 10 days.

MISSILE & SPACE VEHICLE DEPARTMENT

GENERAL ELECTRIC

3198 Chestnut Street, Philadelphia 4, Pa.

Electronic Engineers • Physicists

RESOURCES FOR
THE CHALLENGE
OF SPACE

...General Electric's New $14,000,000 Space Research Center, to be built near Valley Forge Park 17 miles from Philadelphia

General Electric is carrying its tradition of pace-setting electronics research into the field of space vehicle applications, primarily through the agency of its Missile and Space Vehicle Department.

Qualified engineers interested in working in these areas are invited to review the opportunities described on *this and the opposite page.* Those who join us will work in a professional atmosphere with other highly trained and competent people who have taken part in such G-E achievements as the FIRST demonstration of effective space vehicle stabilization control and navigation, and the FIRST measurements in space of earth's magnetic field and infrared radiation.

Upon completion of the Department's *Space Research Center* in suburban Valley Forge, new and unique facilities will be available to our staff, to further long range programs in space electronics.

ENGINEER-TRANSISTOR CIRCUIT DESIGN

BS, EE or Physics with advanced degree desired. Five years' experience in circuit design, information theory and circuit philosophy.

ENGINEER-TELEMETRY DESIGN

Will design and evaluate airborne and ground telemetry, voice and video circuits and components. Thorough knowledge of both transmitter and receiver design, five years' experience; BS, EE required.

DIGITAL CIRCUIT DESIGN

To provide high level technical evaluation of digital techniques as applied to airborne digital and pulse circuitry, EE with five years' experience in this field.

ENGINEER-CONTROLS

Will be responsible for analytical studies in adapted controls, non linear systems and analogue and digital computation. Requires ten years of controls background with BS,EE or related degree.

ENGINEER-DYNAMICS

To conduct analytical studies in the dynamics of rigid bodies as applicable to navigation and control systems. Requires eight years of experience with MS degree in mechanics or physics.

ENGINEER-SYSTEMS ANALYSIS

Requires eight to ten years experience in analytical studies of complex systems, with some control experience. Background in analogue and digital equipment also desirable.

◀ *Check additional openings listed to the left, and write to Mr. Thomas H. Sebring, Div. 53ME.*

MISSILE & SPACE VEHICLE DEPARTMENT

GENERAL ELECTRIC

3198 Chestnut Street, Philadelphia 4, Pa.

COMPUTER SYSTEMS SUPERVISOR

We are seeking an engineer with a record of outstanding achievement in research and development to direct the activities of our Computer Systems Section. As supervisor of this important activity, you will have the opportunity to develop research programs of greatest appeal to you and your staff in the following areas:

- Analysis of Components and Systems
- Advanced Development
  - Digital System Organization
  - Logic
  - Storage
  - Input/Output
- Self-Organizing Systems

As a Foundation staff member you will be joining a mature, independent research organization with a staff of over 600 engineers and scientists contributing to a wide variety of military and industrial research programs.

You will receive a competitive salary plus liberal insurance and retirement benefits in addition to four weeks vacation after one full calendar year of service. Our location in a major midwestern city offers excellent cultural and recreational opportunities.

If this is the unusual professional opportunity you have been looking for, reply in confidence to:

John F. Collins
Armour Research Foundation
of Illinois Institute of Technology
10 West 35th Street
Chicago 16, Illinois

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when you need a man who can command the respect of his associates and subordinates because of his intimate knowledge of and first-hand experience in their fields . . .

when you need a man who is well educated and trained in the specialized fields of knowledge you require . . .

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DESIGN ENGINEERS

check these openings in advanced gyro and electrical components design

In 1949, Honeywell developed and flight tested the floated gyro for control systems. Since then, its Gyro Design Group has become the focal point for a multi-million dollar component development program, supporting the inertial navigation industry. This is, perhaps, the most advanced program of its kind. It has expanded rapidly and now has openings for additional top level engineers.

This group is involved in all fields of gyro design. It works in such areas as *precision gyro and accelerometer design, hydro-dynamic bearings, vibratory mechanisms, precision electric suspension techniques and gyro magnetics.*

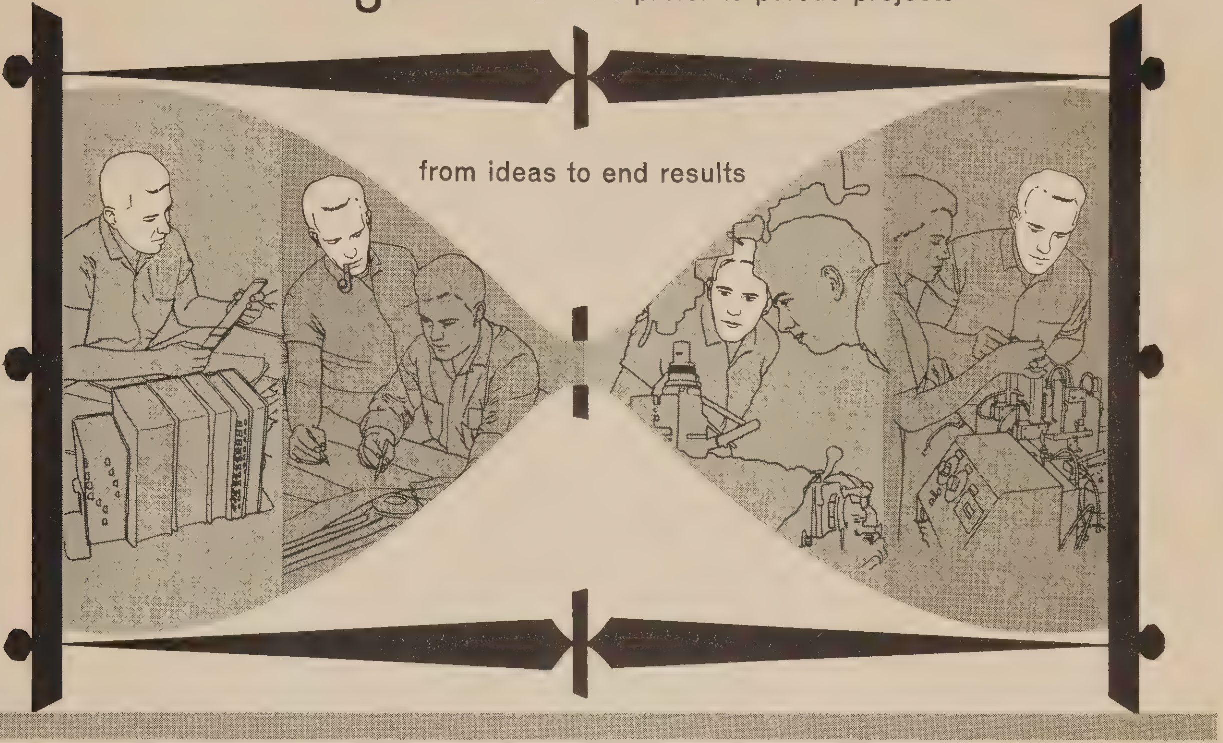
The men needed to fill these positions should be capable of developing advanced concepts for gyros and of following through on their projects. They should have a minimum of two years' (and up to twenty years') experience in such areas as *precision gyro mechanics, servo techniques, digital data handling, electronics packaging, advanced instrumentation,* or *magnetic component design.*

To discuss these or other openings, write Mr. Bruce D. Wood, Dept. 610D, Aeronautical Division, 1433 Stinson Blvd., Minneapolis 13, Minn.

Honeywell
H HONEYWELL Military Products Group

To explore professional opportunities in other Honeywell operations coast to coast, send your application in confidence to H. K. Eckstrom, Minneapolis 8, Minnesota.

T/I S-C wants senior electro-mechanical engineers who prefer to pursue projects


from ideas to end results

You won't find frustrating bottlenecks in TI's immense semiconductor mechanization program. Unhampered progress toward ideal end results is assured because TI permits mechanization engineers to stay with their projects from beginning to end. Hence the remarkably short time interval between conception and production of new TI semiconductor manufacturing machines and the devices they produce.

In a broader sense your work will be a cooperative venture. For at TI S-C you are free to work even in the shop with tool makers, as with all other professional and technical specialists whose talents will help you convert your conceptions into realities. In this ideal working climate your challenging assignments will include design, development and evaluation of mechanical, electronic and electrical mechanization equipment of widely varying types and sizes.

Requirements include a BS or MS in Mechanical or Electrical Engineering with emphasis on mechanical or servo-mechanism design and at least three years in two of the following fields: design of semiconductor test equipment, mechanized semiconductor machinery, computers, servos.

succeed in '60 with T/I

whether applying or not, mail coupon for your copy of TIps *today and learn more about T/I Semiconductor-Components division.*

INTERVIEWS are scheduled for your area. If qualified for this position please send confidential resume immediately to C. A. BESIO, Dept. 111

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P. O. Box 312, Dept. 111 Dallas, Texas

Please send me TIps, containing specific facts about now available T/I S-C assignments *in my field*, and related information.

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My professional field is ____________________

My specialty is ____________________

SENIOR MICROWAVE ENGINEER

You will be given system responsibility for the development of new concepts in the generation, propagation and radiation of microwave power for heating, cooking and curing purposes, in numerous commercial and industrial applications. (Raytheon is one of the few electronics companies whose staff includes systems, advanced development, and design engineers in these fields).

You must have a BSEE or equivalent and should have 8 years of broad design or advanced development experience in the microwave field in order to handle the planned assignments. (Experience in radar development, for instance, or DC power generators or magnetrons.) Since we're looking for an exceptional individual—who will be rewarded accordingly—the deciding factor will probably be your creativeness and ingenuity, as evidenced by: patent disclosures; significant publications; or descriptions of accomplishments not formalized by patents or publication.

MICROWAVE LICENSEE ENGINEER

You will serve as liaison between Raytheon and licensees, assisting in the design of microwave cooking units for these licensees' commercial ovens. This will involve working with the licensees' design engineers to solve such problems as heat, sanitary considerations, microwave distribution, wave modulation, insulation and cost reduction. You will also help translate licensees' suggestions into product improvements.

You should be a senior-level electronics engineer with a BSEE or equivalent and should have 5 years' applicable experience. Background in design of test equipment, high-power modulators, or commercial microwave equipment is especially useful, as is knowledge of magnetrons, underwriters' requirements and FCC regulations. Basically, we're looking for a top design and sales engineer (travel will be limited, however) so salary is commensurate—that is, excellent.

Both positions are in the suburban Boston area and offer attractive cultural, educational and recreational opportunities. Relocation assistance is available. Please phone collect (BIgelow 4-7500) or forward your detailed resume to Mr. Paul R. Alexander, Manager of Professional Personnel, Commercial Apparatus & Systems Division, Raytheon Company, Watertown, Massachusetts.

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COMMERCIAL APPARATUS & SYSTEMS

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We have succeeded in the development of an entirely new concept for the SUCCESSFUL placement of qualified engineers and scientists. If your present position is frustrating, lacking financial reward or if your employer has failed to utilize your full potential why not communicate with us at once. We now have in excess of 4000 senior positions in the $9,000.00 to $35,000 bracket. Some of these positions offer bonus, stock participation, or profit sharing. For confidential consideration submit your resume in duplicate to Mr. Richard L. Berry (MEMBER IRE). Be sure to indicate your salary requirements and location preferences if any. All search fees and expenses paid by our clients.

RICHARD BERRY ASSOCIATES
1014-1015 Commercial Trust Bldg., Philadelphia 2, Penna. LOCust 3-6654

Positions Open

(Continued from page 146A)

ELECTRICAL ENGINEERING

Excellent opportunities for qualified Ph.D.'s in logical design, network synthesis and other areas. Rank and salary commensurate with research and teaching qualifications. Teaching loads at all ranks are low. They are reduced further for those handling sponsored research projects. Each faculty member is expected to develop and maintain a strong research program. Send complete resume including research publications to Chairman, Dept. of E.E., Northwestern University, Evanston, Ill.

ELECTRICAL ENGINEERS

Electrical Engineering staff openings. Both graduate and undergraduate courses. M.S. required, Ph.D. desirable. Modern facilities. Active research program. Write: Joseph C. Michalowicz, Head, E.E. Dept., Catholic University, Washington 17, D.C.

Positions Wanted

By Armed Forces Veterans

In order to give a reasonably equal opportunity to all applicants and to avoid overcrowding of the corresponding column, the following rules have been adopted:

The IRE publishes free of charge notices of positions wanted by IRE members who are now in the Service or have received an honorable discharge. Such notices should not have more than five lines. They may be inserted only after a lapse of one month or more following a previous insertion and the maximum number of insertions is three per year. The IRE necessarily reserves the right to decline any announcement without assignment of reason.

Address replies to box number indicated, c/o IRE, 1 East 79th St., New York 21, N.Y.

ENGINEER

Ph.D., June 1960. 5 years industrial experience, several semesters experience teaching lecture courses at the senior EE level. Interested in teaching and research at progressive EE Dept. Prefer western U.S. Box 2049 W.

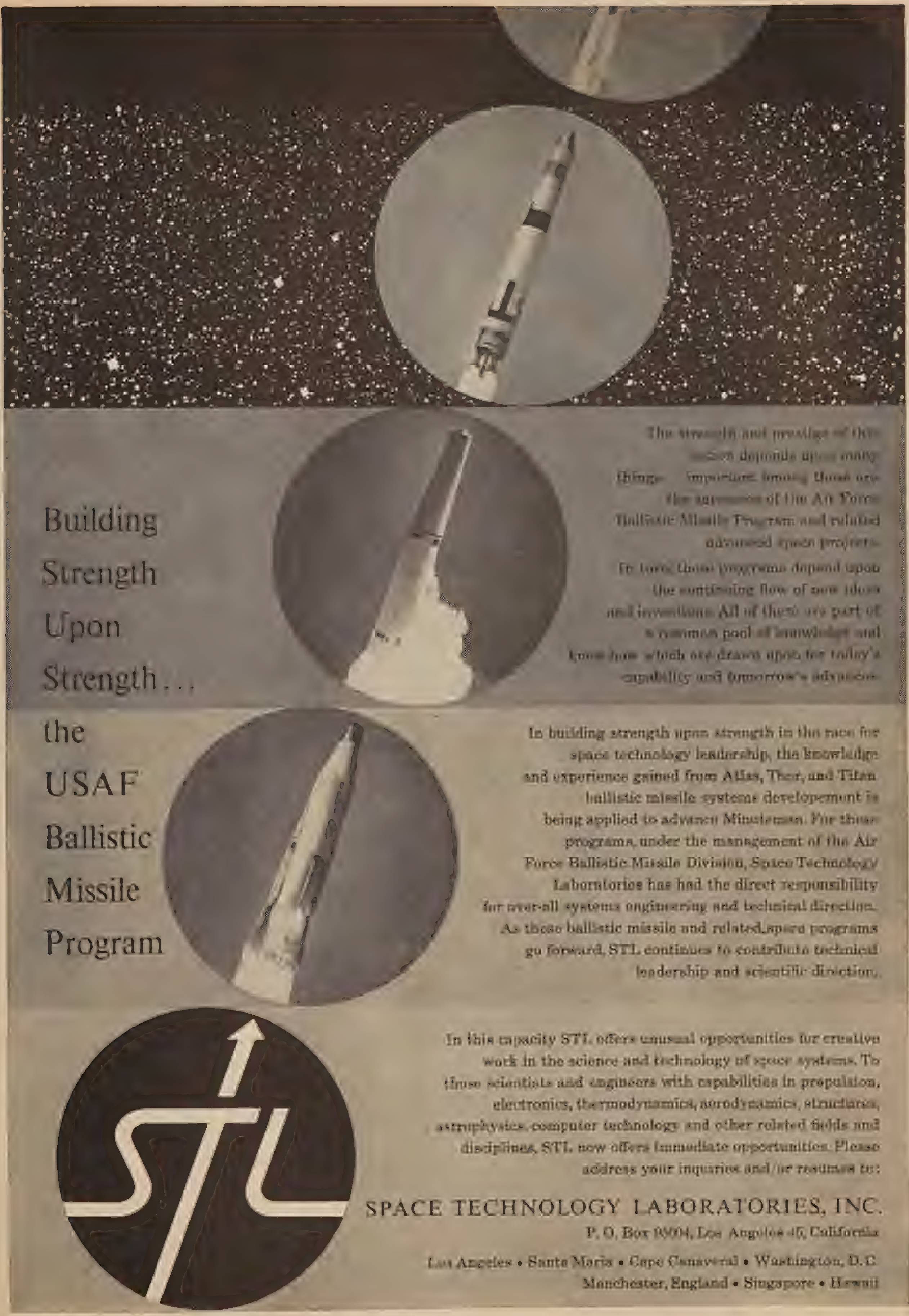
SENIOR ELECTRONICS ENGINEER

BEE., MEE. Had project responsibility in audio, video, computer circuits and equipment; conscientious supervisor. Desires managerial responsibility and substantial challenge. Box 2058 W.

ELECTRONICS ENGINEER

BEE. 1952. MEE. 1955. Age 31. Desires Project Engineering or managerial position with growth potential. 4 years experience, to Project Engineer level, designing and developing large radar systems. Some teaching and research experience. Former Signal Corps officer. Licensed Professional Engineer in New York. Box 2059 W.

(Continued on page 154A)



Building Strength Upon Strength . . . the USAF Ballistic Missile Program

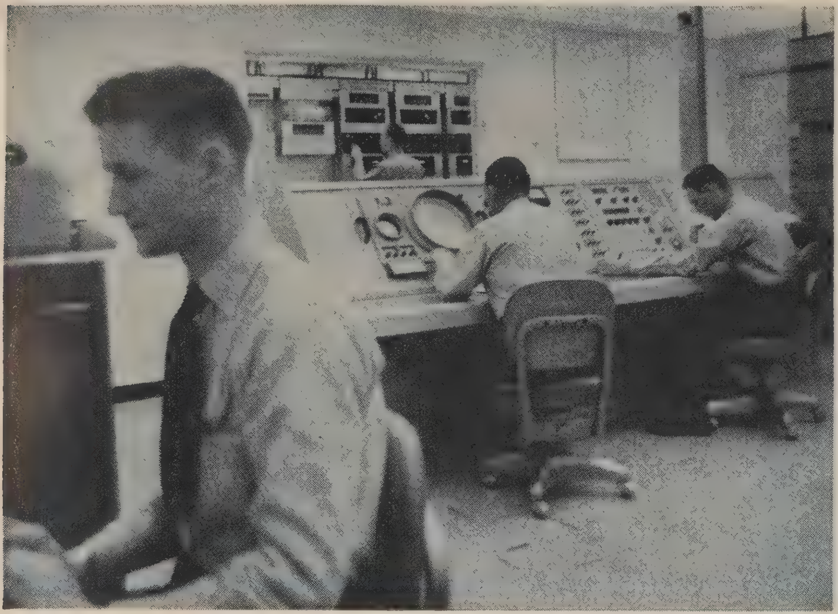
The strength and prestige of this nation depends upon many things— important among these are the successes of the Air Force Ballistic Missile Program and related advanced space projects. In turn these programs depend upon the continuing flow of new ideas and inventions. All of these are part of a common pool of knowledge and know-how which are drawn upon for today's capability and tomorrow's advances.

In building strength upon strength in the race for space technology leadership, the knowledge and experience gained from Atlas, Thor, and Titan ballistic missile systems developement is being applied to advance Minuteman. For these programs, under the management of the Air Force Ballistic Missile Division, Space Technology Laboratories has had the direct responsibility for over-all systems engineering and technical direction. As these ballistic missile and related space programs go forward, STL continues to contribute technical leadership and scientific direction.

In this capacity STL offers unusual opportunities for creative work in the science and technology of space systems. To those scientists and engineers with capabilities in propulsion, electronics, thermodynamics, aerodynamics, structures, astrophysics, computer technology and other related fields and disciplines, STL now offers immediate opportunities. Please address your inquiries and/or resumes to:

SPACE TECHNOLOGY LABORATORIES, INC.
P. O. Box 95004, Los Angeles 45, California
Los Angeles • Santa Maria • Cape Canaveral • Washington, D.C.
Manchester, England • Singapore • Hawaii

alpha has systems management capabilities in many fields



Telecommunication systems . . . such as SAC's "Short Order" . . . are just one of Alpha's areas of capability

Do You Have Diverse Systems Engineering Capabilities?

Alpha functions at the systems level, depending upon reputable and competent manufacturers for the original design of subsystems. Alpha personnel devote their time and energies to the dynamic, economic, and logistic interaction of the individual entities which make up the system. Concentration upon the system as an entity enables Alpha to answer the need for centralized management control of complete systems.

- Alpha current prime contracts include:
- HF SSB communications systems for the Strategic Air Command
- Integrated Fleet Communications System for the U. S. Navy
- Ground based deep space and satellite surveillance systems for the Signal Corps (ARPA) and the Jet Propulsion Laboratory (NASA)
- Telecommunications and command-destruct systems for major missile ranges
- Ground and air transportable electronics systems, including high power communications
- Tropospheric scatter communication system in the Far East for the U. S. Army
- Scatter/microwave communications systems for commercial companies

Alpha assumes responsibility not only for the electronic equipment, but also for the outside plant and other equipments and structures necessary to an operative system. Do you have capabilities in the design, engineering and implementation of complete systems? Write:

C. P. Nelson
Employment Manager

Alpha CORPORATION
A SUBSIDIARY OF COLLINS RADIO COMPANY

SYSTEMS DESIGNERS, ENGINEERS, CONSTRUCTORS, WORLD-WIDE • RICHARDSON, TEXAS • TELEPHONE DALLAS AD 5-2331

Positions Wanted

By Armed Forces Veterans

(Continued from page 152A)

ENGINEER

Desires position not wholly technical involving possible overseas travel. LTJG USNR, Tau Beta Pi, Eta Kappa Nu. Unmarried. BS. and MS. in E.E. from large midwestern universities. Box 2060 W.

ELECTRONIC ENGINEER

BS. 1956; MS. 1957 in E.E., Stanford University. Experience 6 months digital circuitry design, 2½ years in trajectory computation and guidance analysis, including some programming for large digital computer for USAF. Attended special USAF course in Ballistic Missile Fundamentals. Desires position in missile or computer R & D with opportunity for responsibility. 1st Lt. Age 25, married. Avaliable July 1960. Box 2064 W.

ELECTRONIC ENGINEER

BE and MS in E.E. (electronic option) from USC. Phi Kappa Phi, Tau Beta Pi, Eta Kappa Nu. Available July 1960 upon completion 5 years commissioned service with Navy (Lt.). Experience in shipboard electronics, teaching at Naval Academy. Interested in instrumentation, computer application. Southern Calif. area desired (possibly future in Latin America). Age 28, married. Resume upon request. Box 2065 W.

ELECTRONIC ENGINEER

BSEE. 1948. Heavy experience in industry controls and allied fields. Desires managerial position with strong and growing company in the field of industrial electronics. Location anywhere. Box 2067 W.

(Continued on page 157A)

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REQUIRES THE TALENTS OF . . .
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Clevite, a young, fast-growing company offers plenty of room for advancement. Relocation expenses fully paid
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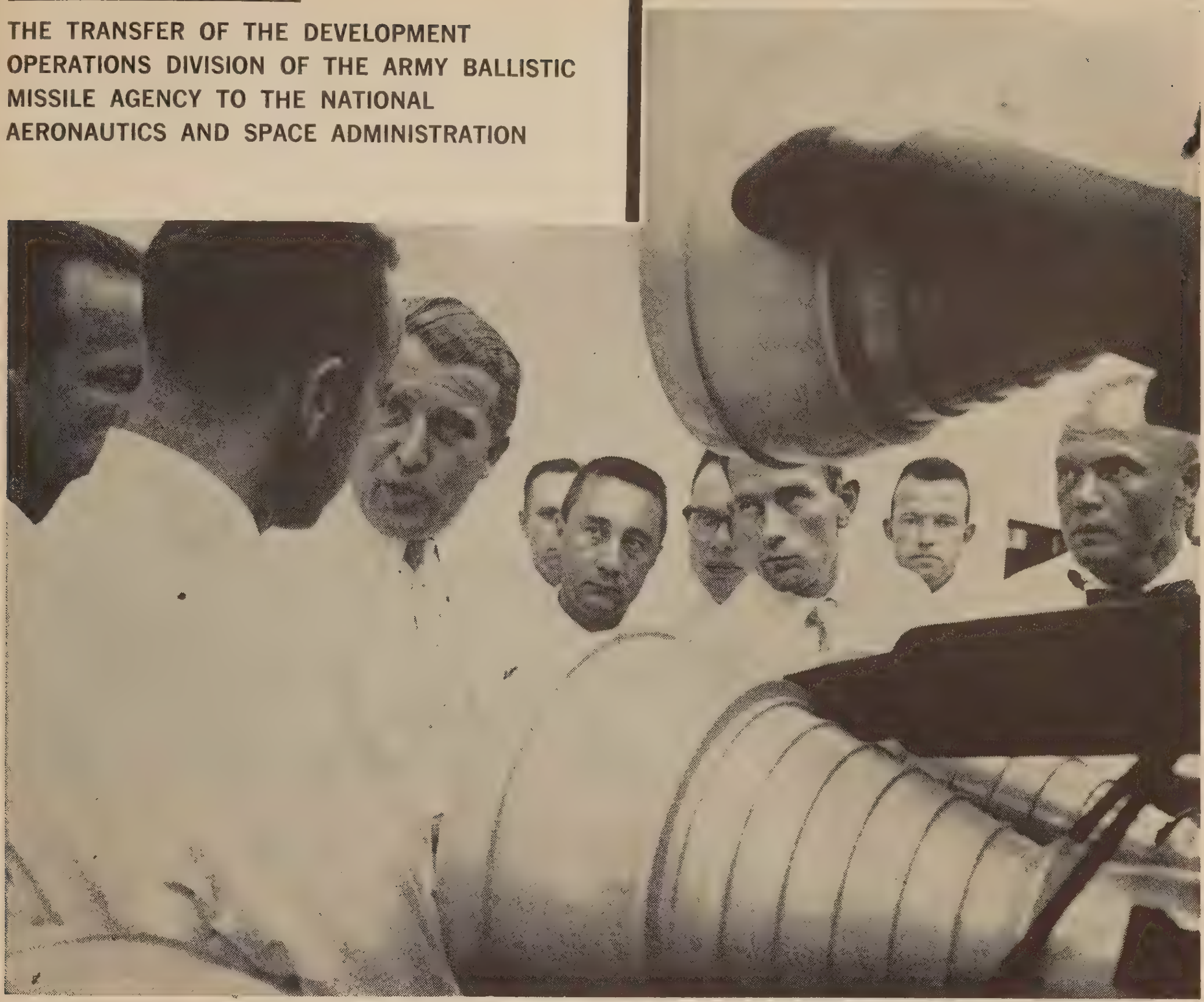
NASA announces . . .

THE TRANSFER OF THE DEVELOPMENT OPERATIONS DIVISION OF THE ARMY BALLISTIC MISSILE AGENCY TO THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION



Dr. Wernher von Braun, director of the new NASA Marshall Space Flight Center in Huntsville, Ala., pictured with NASA's Mercury Astronauts

Dr. Wernher von Braun and his space team join NASA

The National Aeronautics and Space Administration leads the nation's efforts to find, interpret and understand the secrets of nature as they are revealed in the laboratory of space.

This vigorous effort requires boosters for space vehicles which greatly exceed the thrust of any boosters currently available. For this reason, the $100 million Huntsville plant, together with its famous space team, are being transferred to NASA. The new NASA facility in Huntsville will be known as the George C. Marshall Space Flight Center.

NASA is now the largest civilian research organization in the United States. For details about outstanding professional opportunities, address your inquiry to the Personnel Director of any of these NASA centers:

NASA Goddard Space Flight Center
Washington 25, D. C.

NASA Flight Research Center
Edwards, California

NASA George C. Marshall Space Flight Center
Huntsville, Alabama

NASA National Aeronautics and Space Administration

po-si'tion

Problem: Determine positional accuracy of automatic inertial navigation system.

Solution: Celestial check by Nortronics' visual Type 11 Periscope System or submarine Radiometric Sextant, Mark II.

Result: Bird away and on target.

Pioneering by Nortronics' Precision Products Department in the field of navigation and stabilization systems has created unique career opportunities in advanced design, production and applications engineering.

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PRECISION PRODUCTS DEPARTMENT
NORWOOD, MASSACHUSETTS
Field Offices
Highway #46
Teterboro, New Jersey
2486 Huntington Drive
San Marino, California

Positions Wanted

By Armed Forces Veterans

(Continued from page 154A)

ELECTRONIC ENGINEER

BSEE. 1957. 1/Lt. USAF. Electronic instructor while on active duty. Some graduate work completed. Desires an R & D position in the mid-Atlantic area. Age 24, married. 1 child. Box 2068 W.

SALES ELECTRONICS

Experienced sales and engineering background in electronics to distributors. OEM and direct customers. Age 38 with excellent sales record in product and components. Experienced in sales promotion. Desires position with responsibility and future. Box 2069 W.

ELECTRICAL ENGINEER

BSEE. 1958. Lt. (JG) USNR. Completing 2 years as Electrical & Engineer officer afloat and ashore. Experience in repair and maintenance of various types of equipment and in personnel management. Married. Desires position in southwest. Available August 1960. Box 2070 W.

ENGINEERING EXECUTIVE

At 35, holding SBEE and MSEE electronics, and wonderfully settled with family in Honolulu, desires a position in this area. Unusually familiar with resourses, limitations and energetic future of Hawaii. 15 years experience with shipboard, missile and management of Naval Electronics. Box 2086 W.

SENIOR ENGINEER

MS., solid supervisory experience in transistor applications and technology, desires technical or administrative position in Europe with U.S. or European semiconductor manufacturer. Fluent French, some Italian; married with family. Box 2087 W.

SENIOR PROJECT ENGINEER—CHIEF

BSEE. all requirements MS but thesis. Age 36, married, 2 children. 10 years design and project supervision experience in air navigation systems, HF and VHF communications and industrial TV systems. Also teaching experience in transistors. Member IRE and Tau Beta Pi. Prefer location south or southwest. Box 2088 W.

ENGINEERING TECHNICIAN

Graduate of DeVry Technical Institute in Electronic Technology and Design; married; age 26. 5 years experience in radar and TV repair; 17 months experience as Service Manager for large Detroit electronic distributor; wants position with up-and-coming firm that is going places. Opportunity for further study and advancement desirable. Avaliable July 1960. Box 2089 W.

Membership

The following transfers and admissions have been approved and are now effective:

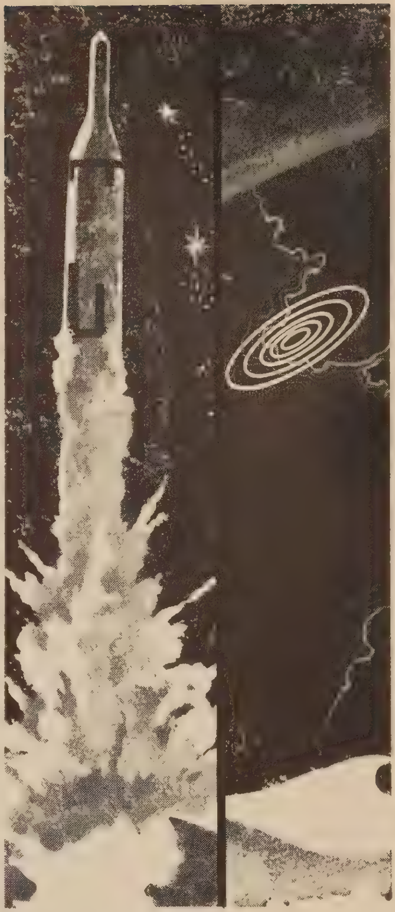
Transfer to Senior Member

Barrack, C. M., Pikesville, Md.
Bates, D. J., Culver City, Calif.
Beecher, D. E., Los Angeles, Calif.
Boesch, P. W., Washington, D. C.
Bull, R. W., Mount Prospect, Ill.
Davis, L. W., Albuquerque, N. Mex.
Feldman, N. E., Los Angeles, Calif.
Finley, J. D., Eau Gallie, Fla.
Gross, V., Bayside, N. Y.
Hendrix, C. E., China Lake, Calif.
Horowitz, J., Brooklyn, N. Y.
Hsu, H., Clay, N. Y.
Jones, H. S., Jr., Washington, D. C.
Kaprelian, E. K., Red Bank, N. J.
Kennedy, D. D., Cincinnati, Ohio
Klingler, D. E., Ann Arbor, Mich.
Koesy, C. B., Panama City, Fla.
Koss, N. A., Wakefield, Mass.
Lofgren, F. W., Medford, Mass.
Miller, D. C., Waldron, Ind.
Mott, H., Raleigh, N. C.
O'Brien, W. C., San Pedro, Calif.
Parvin, R. H., St. Petersburg, Fla.
Pizzicara, D. J., Plainview, L. I., N. Y.
Plait, A. O., Fort Wayne, Ind.
Riebman, L., Huntingdon Valley, Pa.
Roberts, W. L., Rome, N. Y.
Roth, H. H., Roslyn Heights, N. Y.
Rubin, S. W., Long Island City, N. Y.
Shepard, E. S., Sr., Phoenix, Ariz.
Singleton, R. C., Palo Alto, Calif.
Smith, D. S. J., Rochester, N. Y.
Smith, G. W., Littleton, Colo.
Southard, C. D., Endwell, N. Y.
Stephens, J. F., Owensboro, Ky.
Stone, E. W., Syracuse, N. Y.
Weisz, W. J., Skokie, Ill.
White, E. A., Fort Wayne, Ind.
Wolfe, A. E., Lancaster, Calif.

Admission to Senior Member

Billings, A. R., Nedlands, Western Australia
Blair, C. L., Little Silver, N. J.
Bloom, S., Plainfield, N. J.
Buescher, R. H., College Park, Md.
Cahn, H., Asbury Park, N. J.
Cameron, T. J., Lompock, Calif.
Chrupcala, W. J., Burbank, Calif.
Collar, H. W., Sewell, N. J.
Cooney, T. R., Dayton, Ohio
Daly, E. J., Livermore, Calif.
Davies, F. T., Ottawa, Ont., Canada
Del Grosso, V. A., Washington, D. C.
Dousmanis, G. C., Princeton, N. J.
Emerson, W. H., District Heights, Md.
Finkel, M., Rolling Hills, Calif.
Frenzel, R. P., Cazenovia, N. Y.
Graham, J. J., Oaklyn, N. J.
Graul, D. P., Griffiss AFB, N. Y.
Hamilton, J. J., Schenectady, N. Y.
Hannon, R. J., Lexington, Mass.
Harris, R. C., Plainfield, N. J.
Hauser, H., Washington, D. C.
Hernqvist, K. G., Princeton, N. J.
Hey, H. C., Murray Hill, N. J.
Hogan, M. B., Syracuse, N. Y.
Hornfeck, A. J., Cleveland, Ohio
Ivanek, F., Stanford, Calif.
Jones, J. L., Eatontown, N. J.
Klein, R. J., Oak Ridge, Tenn.
Kornei, O., Ossining, N. Y.
Kundu, M. R., Ann Arbor, Mich.
Link, F. M., Westwood, N. J.
Machuta, A. J., Hatboro, Pa.
Malinowski, L. P., Riverside, Calif.
Mandelbrot, B. B., Ossining, N. Y.
Mano, K., Sakurakoji, Sendai, Japan
Marshall, F-H. B., Drexel Hill, Pa.
McColl, D. R. S., Sudbury, Mass.
McGee, J. F., El Paso, Tex.
McReynolds, O. J., Bethesda, Md.
Miller, W. E., Urbana, Ill.
Morita, M., Yokohama, Japan
Nader, J. S., Cincinnati, Ohio
Nimura, T., Sendai, Japan
Ochi, S., Costa Mesa, Calif.
O'Donnell, R. V., Freehold, N. J.
Pawlowski, B. J., Wakefield, Mass.
Pliskin, W. A., Poughkeepsie, N. Y.
Pula, T. J., Baltimore, Md.
Ricketts, M. V., Burbank, Calif.
Rosenbaum, M., San Diego, Calif.
Ruff, D., Washington, D. C.
Schweiger, R. N., Wilmington, Mass.

(Continued on page 158A)



po-si'tion

A NOTE FOR TALENTED ENGINEERS:
We invite your inquiry as to important positions that exist at Nortronics' Precision Products Department (formerly the Military Products Division of American-Standard).

Plan your future with Nortronics' Norwood team and stimulate your professional growth. If you can qualify in one of several electro-mechanical areas you will work on challenging programs with professionally dedicated associates.

FOOTNOTE: *Excellent salaries for qualified engineers in both our Systems and Components Groups.*

Contact E. P. REARDON,
NORTRONICS Precision-Products Department,
Norwood, Massachusetts

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The recent formation of

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marks the beginning of new expansion—entry into new markets and new activities in both military and non-military fields.

On the East Coast, Lockheed Electronics Company has organized 3 operating divisions. Immediate positions are available for experienced engineers and scientists who possess proficient experience in the following activities and who desire unlimited professional growth with a dynamic, new and expanding organization.

Military Systems-Stavid Division

STAVID will continue to expand its present capabilities in military electronics, and will place special emphasis on: Airborne ASW research and development; Sonar; Sonobuoy systems; unique underwater detection devices; advanced radar systems; operations research—systems analysis; ECM and digital computer design.

Information Technology Division

This new division is engaged in the development and marketing of data systems and sub-systems including: data processing, storage and display systems; telemetry; special purpose computers; systems analysis; communications and navigation systems. Special demand for solid-state circuit design engineers with particular emphasis on DC amplifier and low level, low noise amplifier design; VCO and FM discriminator design experience.

Engineering Services Division

(FIELD OPERATIONS) will continue to expand and diversify in the areas of product service, test, evaluation, range instrumentation and operation, high quality engineering and consulting services. Current professional opportunities immediately available on programs involving: experimental data processing equipment; simulators and trainers; radar and navigation systems; missile guidance and associated general support equipment.

If you would like to investigate present and future opportunities in this growing company, you are invited to submit your professional resume in confidence to:

PROFESSIONAL PLACEMENT DEPT. PP

Interviews arranged promptly

LOCKHEED ELECTRONICS COMPANY
PLAINFIELD, NEW JERSEY
PLAINFIELD 7-1600

Membership

(Continued from page 157A)

Smith, D. D., Silver Spring, Md.
Soderquist, G. W., Eau Gallie, Fla.
Stegner, C. B., Verona, N. J.
Sterrett, D. S., Charleston, S. C.
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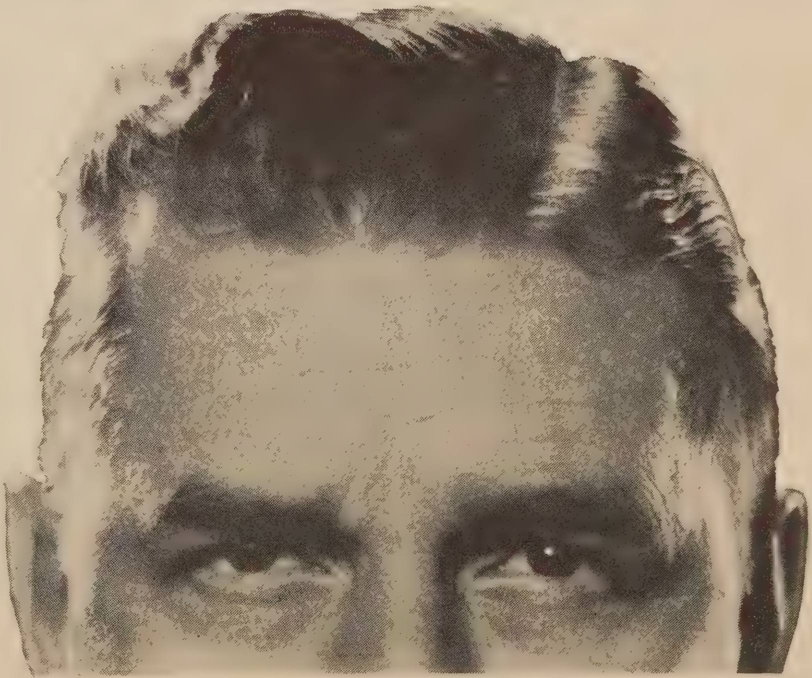

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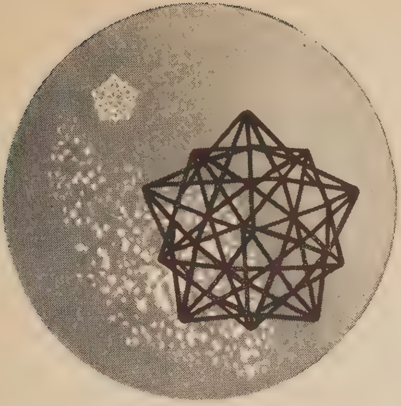

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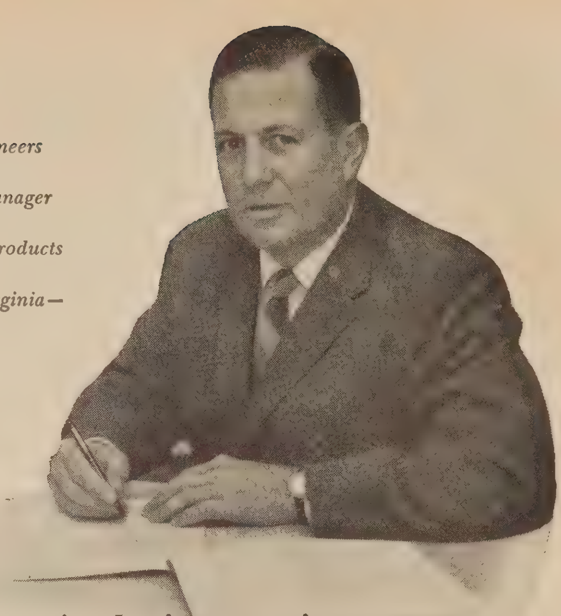

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Grabowski, J. P., Dickson City, Pa.
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Greenberg, Levittown, Pa.
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Gyurko, J. E., Tinley Park, Ill.
Halverson, P. C., Anaheim, Calif.
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Hatch, G. M., Los Angeles, Calif.
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Herin, J. G., Playa Del Rey, Calif.
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Hilton, A. M., New York, N. Y.
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Hodara, H., Morton Grove, Ill.
Holik, F. J., Sharon, Mass.
Holt, A. R., Culver City, Calif.
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Jones, J. C., Apalachin, N. Y.
Jordan, A. G., Pittsburgh, Pa.
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(Continued on page 170A)

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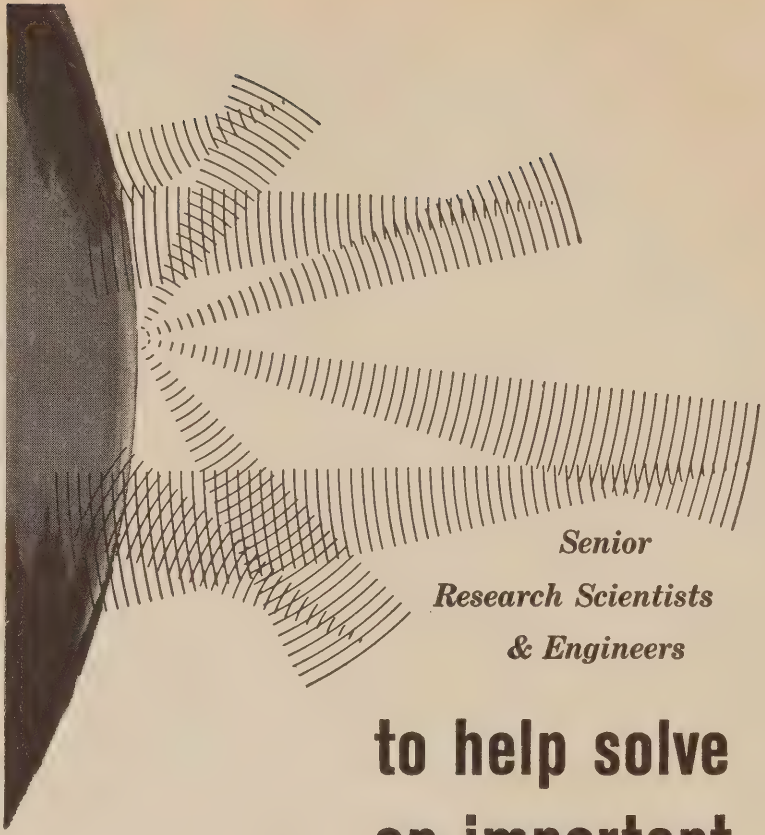

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2 Diversity—20 R&D contracts at time of writing.

3 Stability—substantial production activities as well as advanced R&D.

4 Backlog at beginning of '60—$20,000,000.

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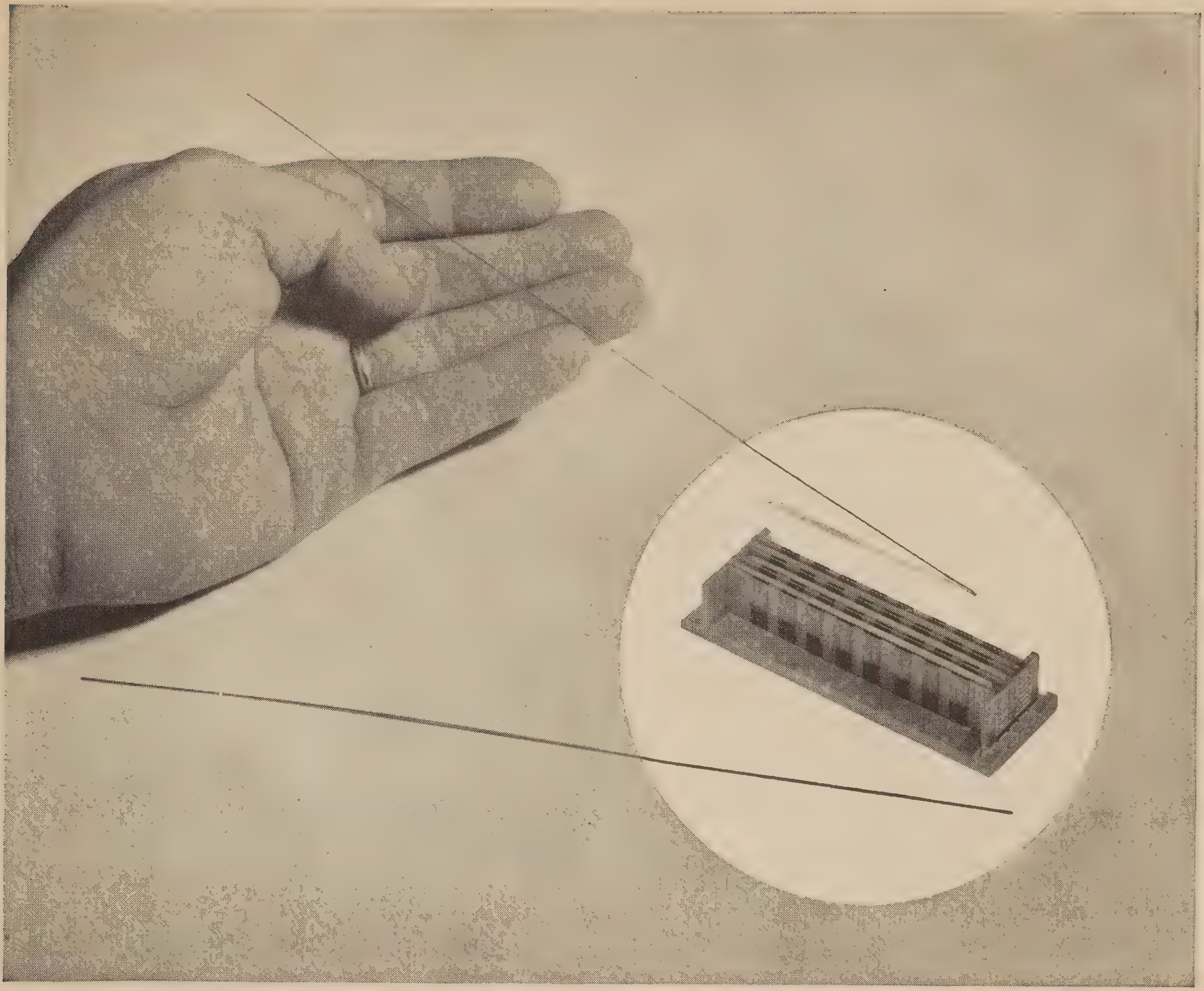

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SOLID STATE PHYSICS: Electro, chemical, and vacuum deposited magnetic films ferrites and ferro-magnetics, advanced magnetic tape studies, electroluminescence-photoconductor investigations.

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(Continued on page 174A)

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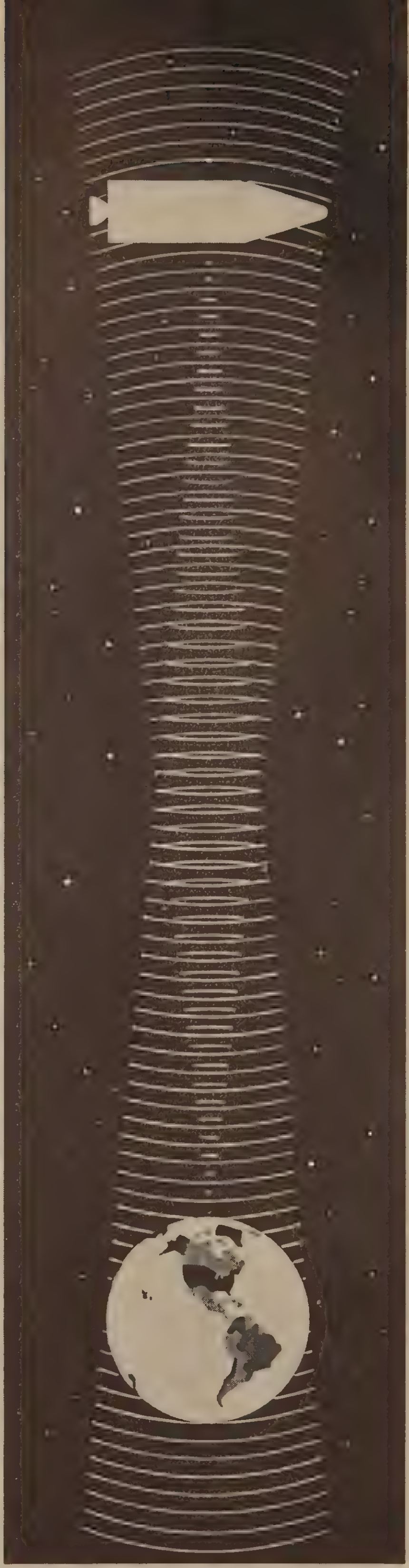

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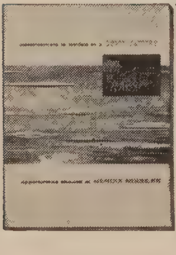

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(*Continued on page 176A*)

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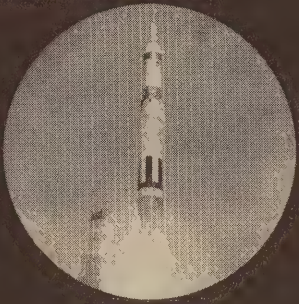

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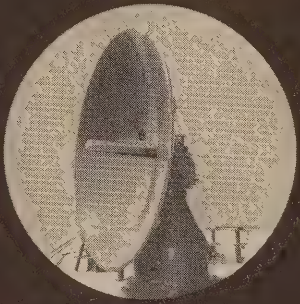

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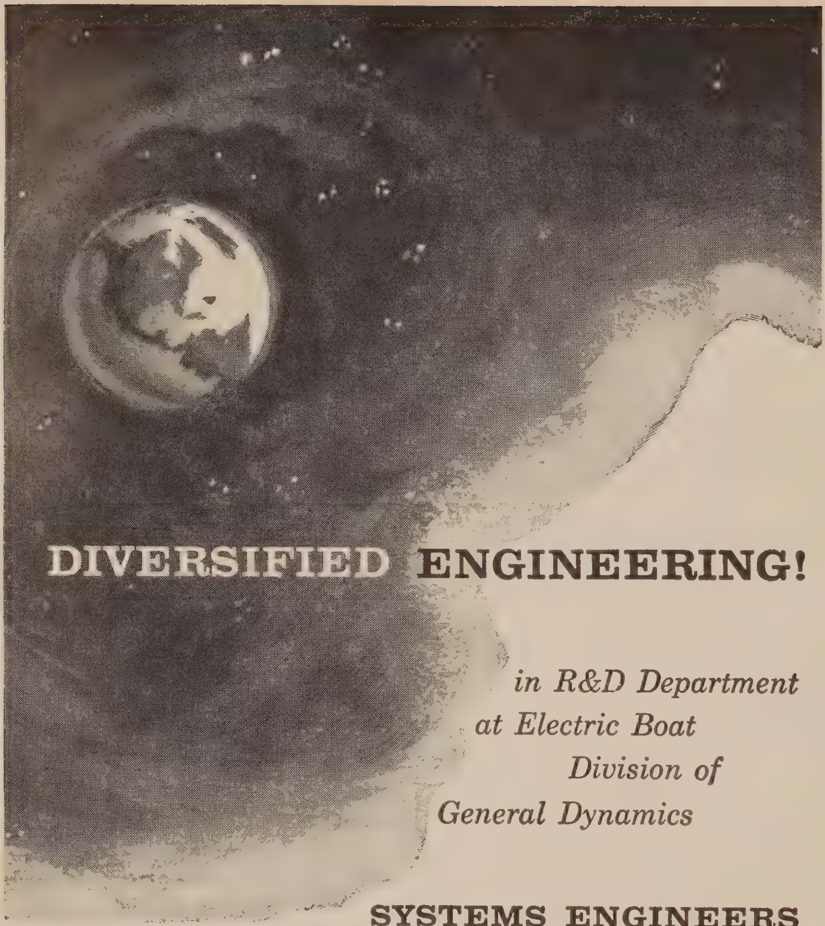

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Membership

(Continued from page 174A)

Admission to Associate

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Bessey, R. C., Melbourne, Fla.
Birbilis, N., Hollywood, Calif.
Boritz, S. L., Biloxi, Miss.
Bourret, R. R., Mountain View, Calif.
Boyd, R. W., Arlington, Va.
Branigan, J. T., Chicago, Ill.
Brennan, P. M., Lincoln Park, N. J.
Brumley, C. C., Fort Huachuca, Ariz.
Buckminster, I. H., Woodstock, N. Y.
Bush, A., Los Angeles, Calif.
Byerley, E. R., Hollywood, Calif.
Cain, C. M., Las Vegas, Nev.
Carroll, G. L., North Andover, Mass.
Carter, C. O., Indianapolis, Ind.
Center, G. A., Mountain View, Calif.
Cenzatti, E., Mariano Comense (Como), Italy
Chaturvedi, G. N., Thana, Bombay, India
Cocker, W. T., Elizabeth, N. J.
Colby, R. J., Chicago, Ill.
Collette, M. M., Antwerp, Belgium
Cooley, G. A., Jr., Chicago, Ill.
Corneretto, A., New York, N. Y.
Crowell, R. J., Panama City, Fla.
Culbert, W. F., Winnepeg, Man., Canada
Daburlos, K. E., Reading, Pa.
Davis, S. B., Houston, Tex.
De Artinano, F. C., Chino, Calif.
De Mambro, J. A., Chestnut Hills, Mass.
Demetrick, J., Jr., Lima, Peru, S. A.
Doty, A. C., Jr., Franklin, Mich.
Dowler, C. E., Modesto, Calif.
Duncan, L. J., Chicago, Ill.
Edwards, G. I., Chicago, Ill.
Fausett, F., Jr., Cincinnati, Ohio
Fink, W. K., Klamath Falls, Ore.
Frazier, M. B., Jr., Memphis, Tenn.
Friedman, T. D., Arlington, Va.
Fukushima, K., Setagaya-ku, Tokyo, Japan
Gish, D. F., Midwest City, Okla.
Goldblatt, E., New York, N. Y.
Gonthier, A. G., Lauzon, Levis, Que., Canada
Gorby, J. H., San Diego, Calif.
Gordon, A., Johnson City, N. Y.
Gordon, F. J., Jr., Hyde Park, N. Y.
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Griffin, G. A., Yonkers, N. Y.
Hammer, R. P., Plainville, Mass.
Hammers, G. A., Visalia, Calif.
Hansen, J. E., Brigham City, Utah
Harrington, J. D., Nashua, N. H.
Harris, R. W., Kensington, Sydney, Australia
Herrel, W. W., Parlin, N. J.
Hikosaka, S., Setagaya-ku, Tokyo, Japan
Hirshberg, L. H., Wakefield, Mass.
Hopler, V. E., Boonton, N. J.
Howard, D. W., Costa Mesa, Calif.
Hrischenko, G., Ottawa, Ont., Canada
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Ieiri, S., Setagaya-ku, Tokyo, Japan
Ipolyi, G., Mineola, L. I., N. Y.
Ishii, A., Setagaya-ku, Tokyo, Japan
Jacobson, F. O., East Cleveland, Ohio
Johnson, R. L., St. Albans, L. I., N. Y.
Kane, J. J., Cambridge, Mass.
Kaufman, H., Lynchburg, Va.
Kirnon, E. M., Brooklyn, N. Y.
Kommel, B. B., Honolulu, Hawaii
Kowalik, F., Jr., Detroit, Mich.
Kurakake, Y., Setagaya-ku, Tokyo, Japan
La Fever, R. C., Wheaton, Md.
Le Blanc, L. F., Corpus Christi, Tex.
Lichty, R. G., Cocoa Beach, Fla.
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(Continued on page 178A)

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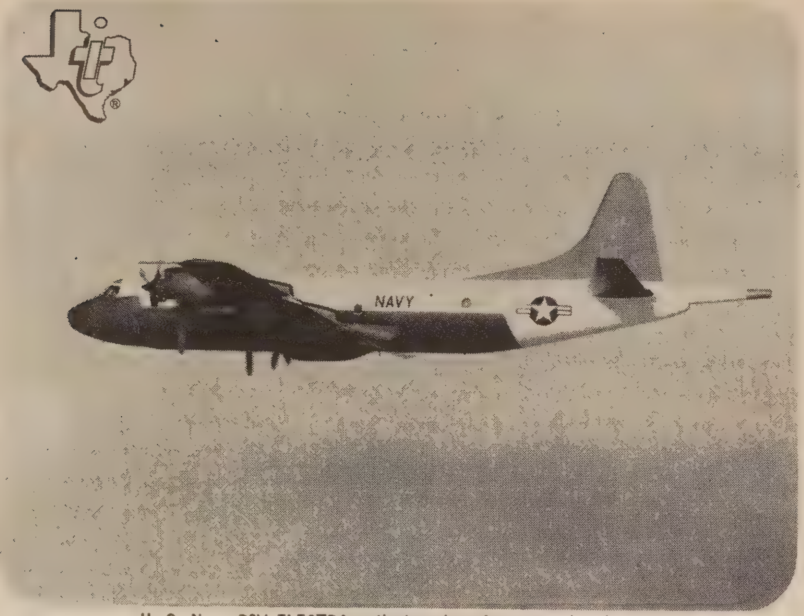

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(Continued from page 176A)

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Milo, P., Alexandria, Va.
Molgaard, N. J., Waltham, Mass.
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Nachlas, S., Houston, Tex.
Nakamura, T., Setagaya-ku, Tokyo, Japan
Osborne, M. H., Philadelphia, Pa.
Owskey, R. D., Alea, Oahu, Hawaii
Patterson, G. B., Anchorage, Alaska
Patterson, G. E., Lancaster, Calif.
Paullus, R. L., Canoga Park, Calif.
Polan, M. J., Forest Hills, L. I., N. Y.
Prisco, L. C., Huntington Station, L. I., N. Y
Proskauer, S. P., Phoenix, Ariz.
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Racine, J. R., Berne, Switzerland
Radnay, L. S., Great Neck, L. I., N. Y.
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Robinson, K. H., Jr., Ridgewood, N. J.
Rohrich, J. F., Philadelphia, Pa.
Rose, J. R., Long Beach, N. J.
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Schacker, D. J., Long Beach, N. J.
Schermerhorn, R. E., Syracuse, N. Y.
Seliga, J., Bedford, Ohio
Simpson, I. L., Baltimore, Md.
Snoblen, J. J., Detroit, Mich.
Spiegel, J., Lexington, Mass.
Stannard, R. E., Los Angeles, Calif.
Steele, C. G., Vancouver, B. C., Canada
Sturdy, R. H., Newton, Mass.
Suba, W. B., Utica, N. Y.
Sulin, J. S., Oakfield, N. Y.
Sumino, R. S., Haddonfield, N. J.
Tansky, R. I., Los Angeles, Calif.
Thomson, E. A., London, Ont., Canada
Trapozzano, V. R., St. Petersburg, Fla.
Tribe, A. C., Jr., Newbury Park, Calif.
Turner, R. A., San Antonio, Tex.
Van Kirk, D. J., Dearborn, Mich.
Van Leer, S. S., Baltimore, Md.
Volgin, V. V., New York, N. Y.
Waks, L. I., New York, N. Y.
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Webber, D. W., Hayward, Calif.
Wheeler, J. B., Jr., Griffiss AFB, N. Y.
Wheeler, K. L., Vancouver, B. C., Canada
Whelchel, W. M., Los Gatos, Calif.
Wise, C. C., Chatsworth, Calif.
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Zarate, E., Tulsa, Okla.
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Professional Group Meetings

Aeronautical and Navigational Electronics

Florida West Coast—February 8

"The Primary Objectives of the IRE," R. L. McFarlan, IRE.

(Continued on page 182A)

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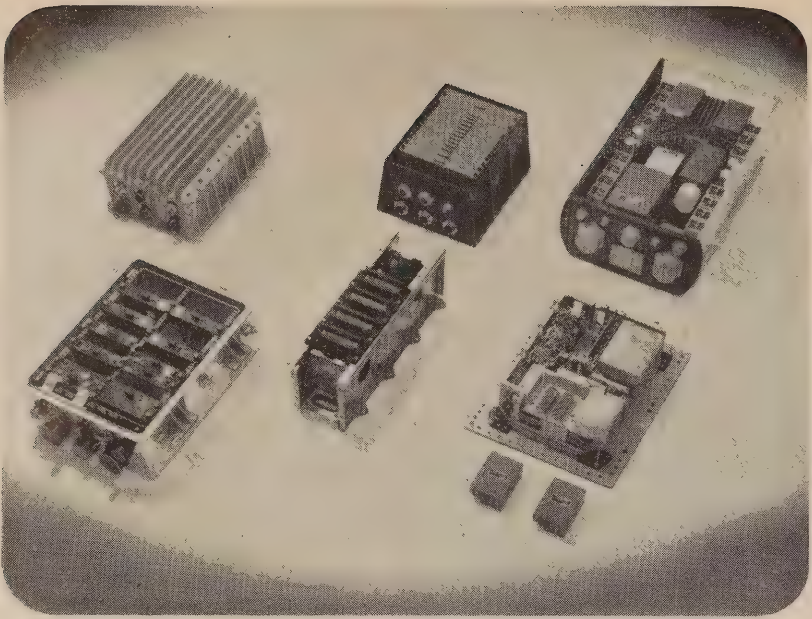

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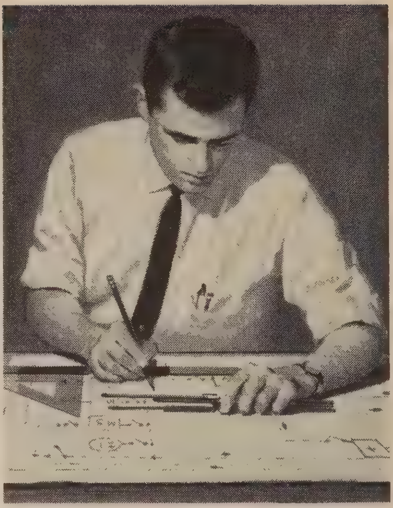

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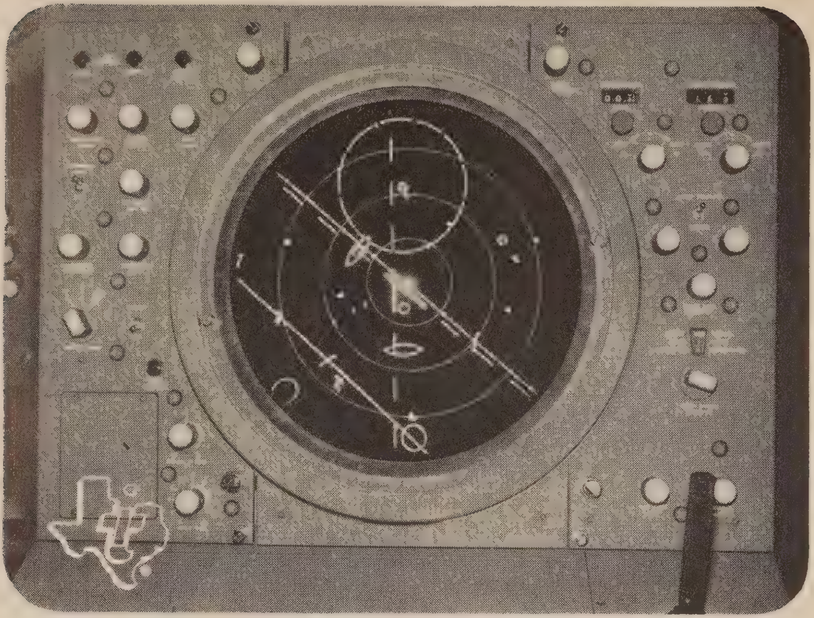

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Professional Group Meetings

(Continued from page 178A)

Philadelphia—January 19

"Sonic Detection Systems and Techniques," J. R. Howard, Herbert L. West, U. S. Naval Air Dev. Center.

Philadelphia—February 17

"Communications in High Intensity Noise," W. F. Meeker, RCA.

ANTENNAS AND PROPAGATION

Boston—February 17

"The Simulation of Plasma by Artificial Dielectrics," W. Rotman, Air Force Cambridge Res. Center.

Orange Belt Subsection—January 19

"Plasma Resonances," W. D. Hershberger, Univ. of California.

AUTOMATIC CONTROL

Boston—December 8

"Two-Mode Servo Controlled Weighing System,: D. Martini, and P. Smith, Feedback Controls D Inc.

"A Unique Target-Position Computer," W. Paradse and D. Stallard, Feedback Controls Inc.

Florida West Coast—February 8

"The Primary Objectives of the IRE," R. L. McFarlan, IRE.

Long Island—February 23

"A Semi Graphical Technique for Designing Third Order Systems," E. Gorczycki, Sperry Gyroscope Co.

Milwaukee—February 9

"Russian Engineering Education with Emphasis on Automatic Control," T. J. Higgins, Univ. of Wisconsin.

BROADCASTING

Houston—January 19

"Tape Automation Utilizing the 'Blue Box'," J. E. Martin, Radio Station KNUZ.

Pittsburgh—January 14

"Principles and Practice of Video Tape Recording," (demonstration of AMPEX recorder) H. E. Ennes, WTAE-TV.

CIRCUIT THEORY

Houston—January 19

"Circuit Theory—Simple Applications of Fourier Series and the Convolution Integral," W. P. Schneider, Schlumberger Well Surveying Corp.

Los Angeles—February 16

"Are Non-Linear Differential Equations Here to Stay, or Has Success Spoiled Mathematical Physics?" R. E. Bellman, The RAND Corp.

(Continued on page 184A)

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Professional Group Meetings

(Continued from page 182A)

COMMUNICATION SYSTEMS

Florida West Coast—February 8

"The Primary Objectives of the IRE," R. L. McFarlan, IRE.

Los Angeles—February 22

"Information Theory—Panel Discussion, S. G. Lutz, E. Rechtin, G. L. Turin, Hughes, Jet Propulsion Lab.

Oklahoma City—January 26

"New FCC Regulations as Affecting Radio Communications," D. F. Holaday, Federal Communications Comm.

Rome-Utica—October 5—7

"Communications—Tomorrow," H. W. Grant, U. S. Air Force.

"Intellectronics," S. Ramo, Ramo-Wooldridge Corp.

Rome-Utica—February 18

"Raytheon Airborne Microwave Platform," H. Letaw, Raytheon Manufacturing Co.

(Continued on page 186A)

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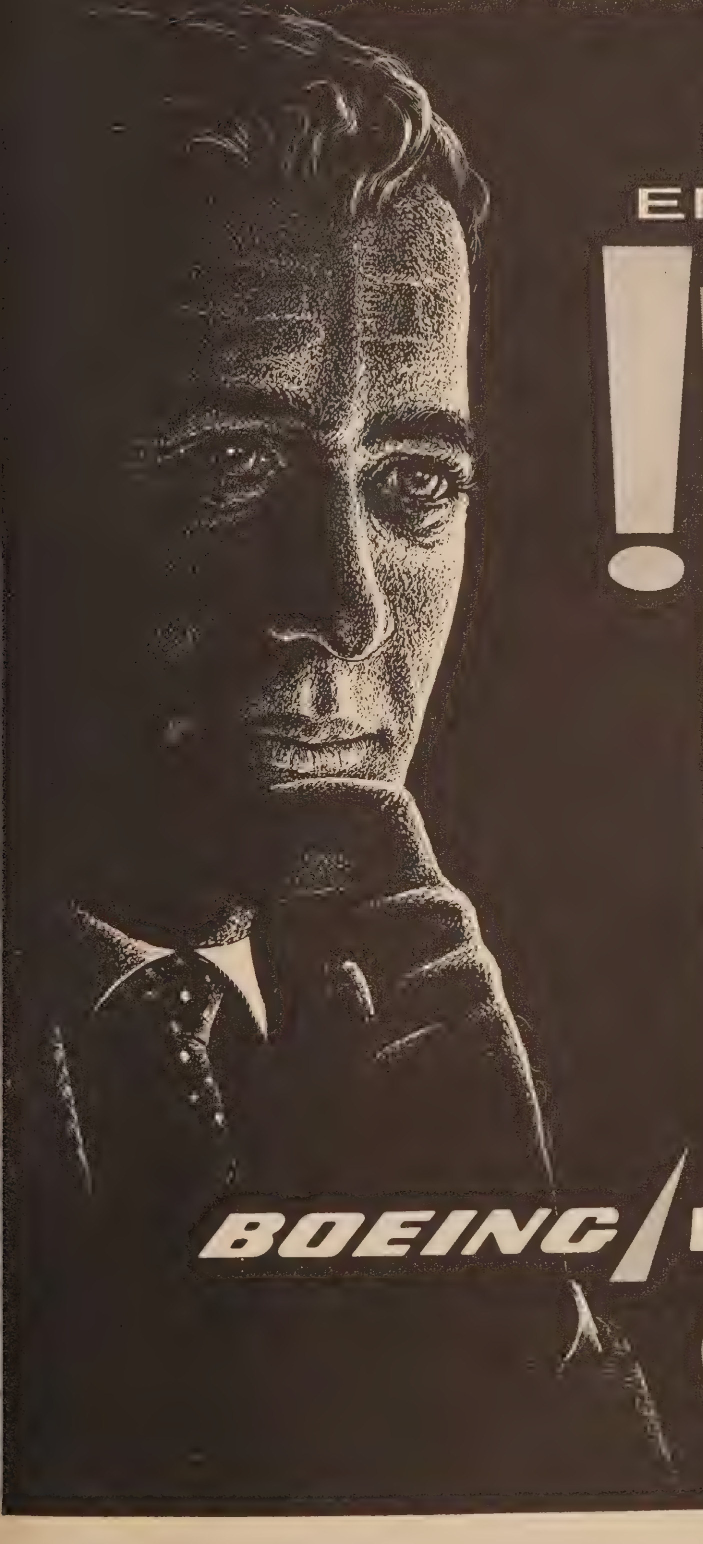

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Professional Group Meetings

(Continued from page 184A)

COMPONENT PARTS

New York—October 20

"The Metallized Electrode Approach to Capacitor Miniaturization," A. Lunchick, U. S. Army Signal Res. and Dev. Lab.

"Metallized Capacitors—Designing for Reliability," W. E. Rieman, The Gudeman Co.

"Use of Metallized Capacitors in Military Airborne Equipment," J. A. MacDonald, General Precision Labs.

"Metallized Capacitors—How Reliable," A. A. Tiezzi, Sprague Elec. Co.

Philadelphia—February 9

"Effects of Nuclear Radiation on Electronic Component Parts and Devices," J. E. Drennan, Battelle Memorial Inst.

ELECTRON DEVICES

Boston—October 26

"The Practical Utilization of Power Transmission by Electromagnetic Beams," W. C. Brown and N. Theodore, Raytheon Co.

Los Angeles—January 28

"Ion Propulsion for Space Flight," J. M. Teem, Calif. Inst. of Technology and Electro-Optical Systems, Inc.

New York—October 1

"A Half Watt CW Helix-Type Traveling Wave Amplifier For 5–6 mm Wavelength," H. L. McDowell, SFD Labs.

New York—November 5

"Recent Developments in Twistor Memories," A. H. Bobeck.

Syracuse—January 19

"Recent Developments in Quantum Electronics," B. Lax, Lincoln Labs.

ELECTRONIC COMPUTERS

Binghamton—January 11

"Status of Electronic Microminiaturization," N. J. Doctor, Diamond Ordnance Fuse Lab.

Detroit—January 18

"The Atlas Ground Guidance System (ANGSQ-33)," R. Tackett, Burroughs Corp.

"The Sage Computer (AN/FST-2)," R. Shipman, Burroughs Corp.

Los Angeles—January 21

"The Tunneling Effect," R. A. Gudmundsen, Hughes Aircraft Co.

"Circuit Applications of Tunnel Diodes," G. Messenger, Hughes Aircraft Co.

(Continued on page 188A)

Demanding Assignments for
Senior Staff Members at

SYLVANIA RSL

Reconnaissance Systems Laboratory on the
SAN FRANCISCO PENINSULA

SENIOR SYSTEMS ENGINEERS

System management responsibility for new programs at Sylvania's Reconnaissance Systems Laboratory offers the broad spectrum of challenging problems involved in large reconnaissance systems. A minimum of 10 years experience is required in progressive assignments leading to and including systems analysis, determination of functional systems requirements and synthesis and integration of subsystems with over-all program requiring knowledge of the capabilities and limitations of techniques and components. Should have background in analysis and synthesis of HF and VHF communication systems employing a variety of modulation techniques and/or digital data handling and automatic control systems.

SENIOR DESIGN ENGINEERS

The design groups in RSL have openings for experienced engineers with six or more years of design and development background in one or more of these areas: communications receivers, digital tuning, RF distribution, DF equipment, magnetic tape recorders, teletype equipment, dynamic displays, demodulators, data transmission, data converters and computers. Opportunities for both technical specialists and supervisors.

THE REWARDS

Work in a compact and growing laboratory which offers the creative engineer the opportunity to grow with an expanding organization. Take advantage of the individual recognition and advancement opportunities of a small organization (approximately 200 employees) with the security, benefits and diversified opportunities of a large corporation. Enjoy the ideal northern California climate in relaxed suburban communities with good schools and recreational facilities for your family. Live within 40 minutes of cosmopolitan San Francisco. Know the advantages of being close to leading universities (Stanford is five miles north of the laboratory).

Complete information may be obtained by writing, in confidence,
to Mr. R. R. Keeffe at:
Sylvania Reconnaissance Systems Laboratory
P. O. Box 188, Mountain View, California

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Government Systems Management
for ***GENERAL TELEPHONE & ELECTRONICS***

GENERAL SYSTEM

I want a "Whatcha-ma-call-it?"
It's a "thinga-ma-jig that ......"

How often have you struggled to remember the name of a component or electronic item. . . . Just could not think quickly what it is called?

YOU CAN FIND IT IN THE IRE DIRECTORY!

because

(1) The IRE Directory classifies products by purpose and use.

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Study it . . . save it . . . work it.

®

THE INSTITUTE OF RADIO ENGINEERS
1 East 79th Street, New York 21, N.Y.

Professional Group Meetings

(Continued from page 186A)

Los Angeles—February 19

"Multiple Program Computer," P. Rosenthal, Remington Rand.

"Multiple Program Computer," R. C. Douhitt, Remington Rand.

New York—September 24

"IBM Serial Paper Document Reader," C. Allen, IBM.

New York—November 18

"Microwave Computing Techniques," P. Isaacs, Sperry Gyroscope Co.

Pittsburgh—October 15

Panel Discussion on Algol.

Pittsburgh—November 9

"Computer Chess Playing Programs," H. A. Simon, Carnegie Inst. of Technology.

Pittsburgh—December 3

"An Introduction to Robotics," L. G. Jones, Westinghouse Air Arm Div.

San Francisco—January 26

"The G.E. ERMA System—Evolution and Function," J. Leventhal, G.E. Computer Dept.

(Continued on page 190A)

ELECTRONIC DESIGN ENGINEERS

The location of your job is important to your family. Professional growth is important to you. To satisfy both of these very important needs why not consider a career with Sperry Products Company.

We are located on beautiful Lake Candlewood in Danbury, Connecticuut, only 65 miles from New York City.

If you have a minimum of 2 years experience in pulse circuitry and general electronics, we feel you will qualify in the field of instrumentation for ultrasonic testing. Transistor experience also desirable.

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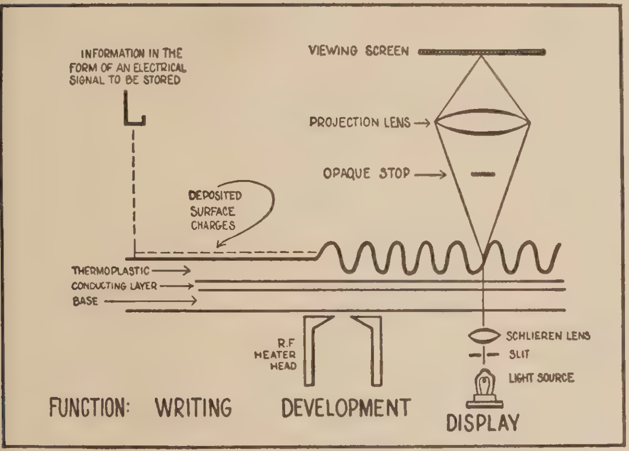
Join General Electric's Electronics Laboratory In Exploiting a Major State-of-the-Art Advance Promising Long-Term Impact on Many Technologies

THERMOPLASTIC RECORDING



BREAKTHROUGHS are frequently talked about, infrequently accomplished. An article appearing in the December issue of *The Journal of Applied Physics,* written by Dr. W. E. Glenn of General Electric's Research Laboratory, has stimulated the imagination of the scientific/technological community. Titled *Thermoplastic Recording,* it describes a revolutionary new method of recording electrical signals. This process makes it possible for information to be written at extremely high density by means of an electron beam on a film consisting of a low melting thermoplastic material. Data can be projected as a black and white or full color image, or it can be converted to an electrical signal. The tape can be readily erased and reused. Summarizing, *Thermoplastic Recording* provides the equivalent of a high resolution, reusable "photographic" film developed by non-chemical means in the fraction of a second.

New Programs Utilizing invention and innovation, the Electronics Laboratory at Syracuse, New York is now engaged in a growing number of programs proving the feasibility of this new process for military and commercial applications which include direct image photography, projection displays, wideband analogue recording, sonar and radio signal correlation and processing.

Anti-Submarine Warfare Program Another program of current interest includes efforts devoted to submarine detection and classification by means other than sonar, secure underwater communications and submarine-to-aircraft communication.

Professional Opportunities Highly creative and experienced engineers and physicists are required to accomplish the objectives of these ambitious programs. Major areas of professional interest should include one or more of the following areas listed to the right. ⏵

A reprint of Dr. Glenn's article describing in detail the Thermoplastic Recording Process *is available upon request.*

- Geometrical, Physical and Electron Optics
- Circuit Design
- Mechanical Design
- Vacuum Technology
- Feedback Theory • Radar
- Oceanography • Television
- Sound Propagation
- Surface Physics • Sonar
- IR Phenomena

Additional openings in these areas:

- Materials • Circuits
- Devices • Systems
- Equipment

For further information on current openings write in strict confidence to Mr. Robert Mason, Dept. 53-ME

ELECTRONICS LABORATORY

GENERAL ELECTRIC

Electronics Park, Syracuse, N. Y.

INERTIAL SYSTEMS DEVELOPMENT

..... there are opportunities at Honeywell Aero for the engineer or scientist who is interested in participating in this growing field of technology. While specific inertial systems experience is desirable, you may also be qualified by your background and/or related experience for activities in the inertial systems development at this time. Specific openings include:

SYSTEMS ANALYST

Mathematician or engineer with strong background in vector analysis, operational calculus, matrix algebra and related techniques. To carry out analysis of inertial systems configurations including error evaluation.

DIGITAL SYSTEMS AND LOGIC DESIGNER

Familiar with digital logic techniques at current state of the art; capable of organizing computing systems to perform various tasks including logical design and critical parameter specification.

ELECTRONIC ENGINEER

Electrical engineering degree plus experience in miniaturized semiconductor electronics development. To design servo, pickoff, and other electronics for use with gyros and accelerometers.

ENGINEERING PHYSICIST

Physicist with practical and theoretical understanding of mechanics, magnetism and electricity to analyze and develop inertial sensors of novel and original design.

To discuss these or other openings, write Mr. R. O. Maze, Chief Engineer, Marine Systems Group, Dept. 610C, Aeronautical Division, 1433 Stinson Blvd., Minneapolis 13, Minn.

Honeywell
H Military Products Group

To explore professional opportunities in other Honeywell operations coast to coast, send your application in confidence to H. K. Eckstrom, Honeywell, Minneapolis 8, Minnesota.

Professional Group Meetings

(*Continued from page 188A*)

"The G.E. ERMA System—Hardware and Performance," C. Tucker, G. E. Computer Lab.

Washington, D. C.—February 10

"Some Recent Developments in Character Recognition Machines," J. Rabinow, Rabinow Engineering Co., Inc.

ENGINEERING MANAGEMENT

New York—December 17

"The Gentle Art of Encouraging Creativity," T. Allison, Weston Elec. Inst. Corp.

San Francisco—February 9

"Engineers' Management: Short Course for Wives," J. V. N. Granger, Granger Associates.

Twin Cities—October 22

Panel-Project Evaluation from R&D Through Shipping, F. Mullaney, Control Data Corp.; B. Kappel, Rosemount Engrg.

Twin Cities—January 28

"Revolution in the Filing Cabinet," D. Lake, Remington Rand Univac.

ENGINEERING WRITING AND SPEECH

Boston—December 2

"Engineering Writing and Speech Techniques for Computer Customer Training," J. J. Davin, Sylvania Electric Prod. Inc.

Boston—February 23

"Use of Motion Picture Techniques in Preparing Engineering Reports," M. H. Read, Bay State Film Prod. Inc.

INFORMATION THEORY

Boston—October 15

"The Coding Problem in Genetics," C. Levinthal, MIT.

INSTRUMENTATION

Long Island—February 16

"Human Factors in Instrument Design," A. Goldman, Republic Aviation Corp.

Los Angeles—February 3

Tour of Shell Chemical Plant.

MEDICAL ELECTRONICS

Los Angeles—January 21

"Effect of Ionizing Radiation on the Living Cell," L. R. Bennet, UCLA Med. Center.

"Technique of Measuring Ionizing Radiation in Living Tissue," L. Gardner, Litton Ind.

Los Angeles—February 18

"Current Instrumentation Problems in Anesthesiology," V. Brechner and R. Bauer, U.C.L.A. Medical Center.

New York—November 5

"An Implantable Self-contained Pacemaker for the Correction of Chronic Atrioventricular Block," W. Greatbach, Taber Instrument Co. and W. M. Chardack, Buffalo School of Medicine and Chief, Surgical Service, VA Hosp.

MICROWAVE THEORY AND TECHNIQUES

Baltimore—February 10

"Millimeter Waveguides," D. D. King, Electronic Communications Inc.

Boston—February 25

"Microwave Applications and Circuit Principles of Tunnel Diodes," M. E. Hines, Bell Telephone Labs.

Long Island—January 21

"Geometrical Methods of Solving Antenna Problems," E. G. Fubini, Airborne Inst. Labs.

No. New Jersey—January 27

"Atomic Clock," M. Arditi, ITT Labs.

Washington—January 12

"Parametric Amplifiers," R. S. Engelbrecht, W. W. Mumford, Bell Telephone Labs.

MILITARY ELECTRONICS

Long Island—January 12

"Strategy of Deterrence," H. Davis, Dept. of Defense.

Los Angeles—September 23

"Air Force Ballistic Missile Training Program," A. R. Sult, USAF Air Force Ballistic Missile Div.

Los Angeles—November 24

Paper and Panel Discussion: The Economic Challenge to the Military Systems Engineer, F. S. Pardee, Panel Moderator: F. G. Suffield, Panel Members: T. W. Johnson, W. E. Sweeney, Commander USN; R. S. Isensen, Lt. Col. USA; S. Greene, Lt. Col. USA.

North Carolina—February 11

"Inertial Navigation," D. R. Shelor, N. Carolina Labs. of B. T. L.
"Fundamentals of Gyroscopics," J. F. Hartnett, Western Elec. Co.

NUCLEAR SCIENCE

Oak Ridge—January 21

"Ferrites and Pulse Transformers," P. E. Dicker, Aladdin Electronics Co.

(*Continued on page 196A*)

MORE BANG
PER DOLLAR FROM
THE LAND OF THE
SHELTERING PALMS

Down where the lakes are only minutes away and the sea shore's just an hour's drive, Martin engineers came up with what is called a "pilot's missile"—the air-to-surface Bullpup. It requires no more special handling than a round of ammunition. It gives the biggest bang per dollar in U. S. missilery.

Bullpup, operational with the Navy (GAM-83B in R&D with AF), was designed and developed at Martin in sunny Florida. Bullpups are now rolling off production lines for both the Navy and Air Force.

Other Martin-Orlando prime contracts include: Lacrosse, Missile Master, and Pershing.

We think Martin-Orlando is doing outstanding work because it has outstanding engineers and scientists . . . and because it has facilities second to none . . . *and because the man who can swim or sail with his son in the evening brings renewed energy and purpose to his job.* If you feel the same way about it, you'll feel at home in Orlando.

Write: C. H. Lang, Director of Employment, The Martin Company, Orlando 6, Florida, for a fully descriptive booklet, "Portrait of a Missile Maker."

CURRENT OPENINGS for engineers in these areas: ground and airborne electronics • advance design • systems • aerodynamics • quality and test • reliability • electronic manufacturing . . .

WORK IN THE CLIMATE OF ACHIEVEMENT

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ORLANDO

MICROWAVE
TUBE R&D

The Electron Tube Division of Litton Industries has an international reputation for its capability in translating advanced concepts into microwave devices of high reliability. In part this is due to management by experienced engineers and, as a design engineer here, you will have well qualified support people on your team.

You will be working for a large company but...

You will be working in a small group on the product of your choice—TWT's, Superpowered Klystrons, crossed field amplifiers, or other sophisticated microwave devices.

Choose research or design and development, whichever field interests you most.

The location is in the San Francisco Bay Area. Your children will belong to one of the nation's great elementary school systems. You, yourself, will be close to all the cultural activities of San Francisco, the Berkeley campus of the University of California, Stanford University, San Jose State College, and the University of Santa Clara.

Openings exist for Senior, Project and Junior Engineers. Junior Engineers need have no experience beyond their baccalaureate in E.E. or Physics.

We assist with relocation expenses. Interviews may be arranged by writing, or telephoning collect to:

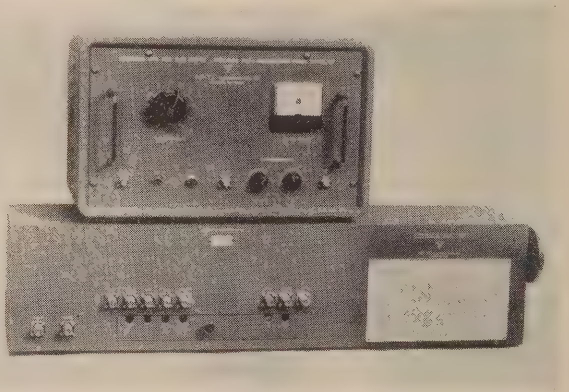
Mr. Thomas A. Fike
960 Industrial Road
San Carlos, California
LYtell 1-8411

LITTON INDUSTRIES
Electron Tube Division
San Carlos, California

(Continued from page 42A)

Precision Phase Detector

This instrument was designed by **Ad-Yu Electronics Lab., Inc.,** 249 Terhune Ave., Passiac, N. J., for precision phase measurement. Based on a comparison principle which enables accurate measurement of phase angle at high frequency, it consists of a coaxial continuously variable delay line and a sensitive phase detector. The continuously variable delay line is used to shift the phase of the unknown signal until zero output is reached on the phase detector. The instrument is convenient for measuring frequency characteristics of radar amplifiers, RF cables, transmission networks and performance of location finding systems. In addition to measuring phase angle between two sine waves, this instrument can be used to measure phase angle of a pulse modulated sine wave or a continuous sine wave, or whether two pulse modulated sine waves are coincident.



The specifications are as follows: The accuracy is ±0.05° or ±1% of the dial reading up to 1000 mc. The resolution is less than 0.01 micromicrosecond; the smallest phase angle which can be read on the dial is less than $10^{-14}\times 360\times$frequency in cps. The time delay of the continuously variable delay line is adjustable from 0 to 1.4 millimicrosecond. Two step variable delay lines have total delay of 37.5 millimicroseconds in E_1 channel and 7.5 millimicroseconds in E_2 channel (in steps of 1 millimicrosecond). The frequency range is 200 to 1000 mc; the upper limit can be extended with relaxing accuracy, the lower limit is restricted only by the phase range as stated. The minimum input signal depends on the sensitivity of the receiver; approximately 20 microvolts for receiver having 5-microvolt sensitivity, and approximately 3 volts minimum is recommended for using panel meter as indicator. The characteristic impedance is 50 ohms nominal for input and output; type N connectors are used throughout.

Repetitive Operation Feature For Analog Computers

A new product which adds another dimension to the art of analog computation has been announced by **Electronic Associates, Inc.,** Long Branch, N. J. High Speed Repetitive Operation is now available as an accessory for all PACE 231R Analog Computers. This addition provides the operator with an accurate, versatile means of solving a variety of engineering problems that would be difficult through "real time" techniques alone. To obtain an optimum design in a problem with several variables, a great many problem runs are required. These are normally drawn on automatic recorders where speeds are limited by the mechanical characteristics of the recorders. With repetitive operation, the solution appears as a continuous plot on the 17 inch display screen. The effect of a change in the problem variables can be observed immediately on the display screen, without the necessity of resetting the equipment and drawing additional plots. When the optimum design is reached, the computer may be switched back to real time operation so permanent plots can be made of the final and more detailed solution. High Speed Repetitive Operation is par-

(Continued on page 194A)

New temperature controlled MICROSTACK® meets

-55°C to +85°C

MILITARY REQUIREMENT

MICROSTACK

The General Ceramics MICROSTACK, one of the most important advances in memory core packaging, now operates in a temperature range of from —55°C to +85°C. Core characteristics remain constant. By maintaining temperature stability inside the MICROSTACK unit, General Ceramics engineers have developed a memory core package that is smaller, more rugged, requires no external cooling or heating, and meets MIL shock and vibration specifications.

For additional information, please write on company letterhead. Address inquiries to Section P.

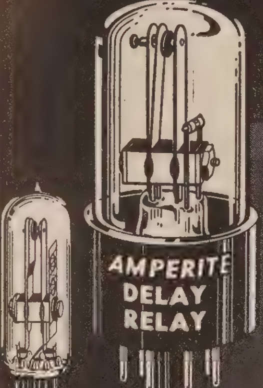
A DIVISION OF
INDIANA
GENERAL
CORPORATION

APPLIED LOGIC DEPARTMENT
GENERAL CERAMICS
KEASBEY, NEW JERSEY, U.S.A.

TECHNICAL CERAMICS, FERRITE AND MEMORY PRODUCTS

AMPERITE
PREFERRED
by design engineers—because they're
MOST COMPACT • MOST ECONOMICAL
SIMPLEST • HERMETICALLY SEALED

Thermostatic
DELAY RELAYS
2 to 180 Seconds



Actuated by a heater, they operate on A.C., D.C., or Pulsating Current.

Hermetically sealed. Not affected by altitude, moisture, or climate changes.

SPST only—normally open or closed.

Compensated for ambient temperature changes from —55° to +70° C. Heaters consume approximately 2 W. and may be operated continuously. The units are rugged, explosion-proof, long-lived, and—inexpensive!

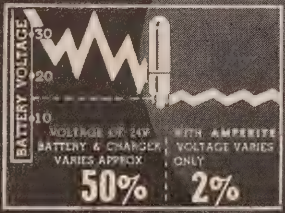
Also — Amperite Differential Relays: Used for automatic overload, under-voltage or under-current protection.

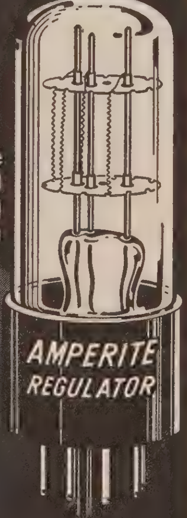
TYPES: Standard Radio Octal, and 9-Pin Miniature . . . List Price, $4.00.
Standard Delays

PROBLEM? Send for Bulletin No. TR-81

BALLAST
REGULATORS

Amperite Regulators are designed to keep the current in a circuit automatically regulated at a definite value (for example, 0.5 amp.) . . . For currents of 60 ma. to 5 amps. Operate on A.C., D.C., or Pulsating Current.





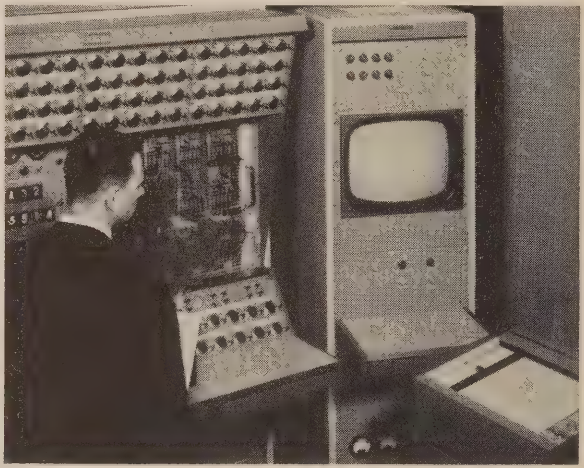
Hermetically sealed, they are not affected by changes in altitude, ambient temperature (—55° to +90° C.), or humidity . . . Rugged, light, compact, most inexpensive . . . . List Price, $3.00.

Write for 4-page Technical Bulletin No. AB-51

AMPERITE CO. Inc., 561 Broadway, New York 12, N. Y.
Telephone: CAnal 6-1446
In Canada: Atlas Radio Corp., Ltd., 50 Wingold Ave., Toronto 10

(Continued from page 192A)

ticularly well suited to problems involving the simulation of servo mechanisms, optimization of chemical, petro-chemical and physical systems, and the solution of boundary-value and eigen-value problems.



A computer equipped with High Speed Repetitive Operation can be operated either repetitively or as a real time simulator at the throw of a switch without degradation of its real time accuracy. Pre-patch panel arrangements remain the same in either repetitive or real time operation and do not require the use of more amplifiers than on real time studies.

Computing times of from 10 to 80 milliseconds are available and may be controlled from either the Repetitive Operation Control Unit or the Display Unit. Both stepped and continuously variable control of computer time are provided to permit the operator to obtain maximum length of solution and avoid overloads.

The display unit consists of four chassis units in a single bay EAI rack and allows simultaneous viewing of eight problem variables plotted against time or seven variables plotted against an eighth on the 17 inch screen. In the Display Unit, 21 voltage calibration lines are references to computer voltage within 0.1%. Time lines are generated by a crystal oscillator accurate to 0.05%.

Typical Applications

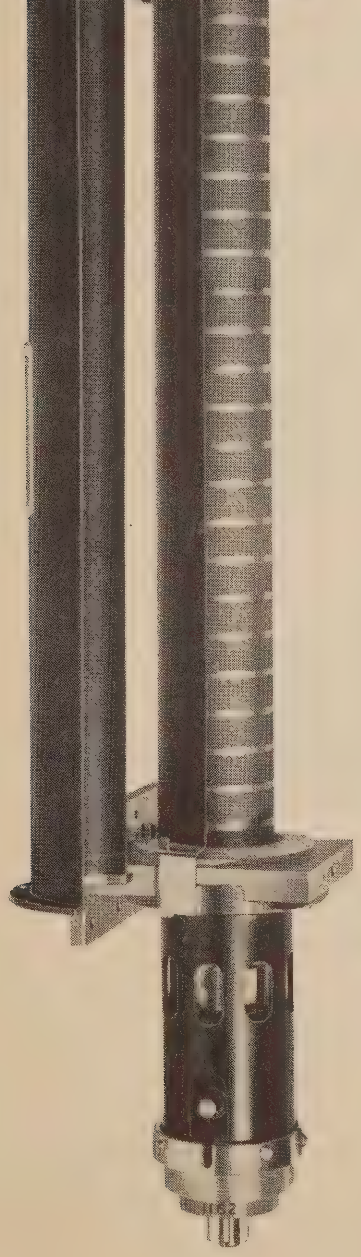
System Optimization

Usually, in the design of a system, certain compromises are necessary in the selection of parameter values which give the best over-all performance. The choice of these compromise values is often based on many repeated runs through the problem. When there are several parameters which can be varied, a large number of runs are required. High Speed Repetitive Operation provides the designer with this larger number of runs in a very short time. The variation of the system performance with each parameter is easily observed. By programming on the computer the selected criterion for optimization, the designer is able to observe the deviation of the performance for a particular choice of parameter values from optimum. With this capability, the designer is able to examine the performance over wide ranges of the parameter. This then facilitates his selection of the true "optimum" and avoids the danger of his being misled toward false "optimums."

Boundary Value Problems

Consider the problem of solving a higher order differential equation where final conditions rather than initial conditions are known. The solution then requires the selection of one or more initial conditions which will yield the proper final values. This requires iterative solution which can be readily accomplished with High Speed Repetitive Operation. The final values are constantly on the display screen and the operator simply varies the initial condition potentiometers to obtain a match at the other boundary. This technique is, of course, applicable to a problem for which the conditions are known anywhere in the solution region.

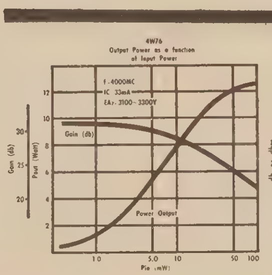
package-type TWT power amplifiers with NEC's new long life cathode

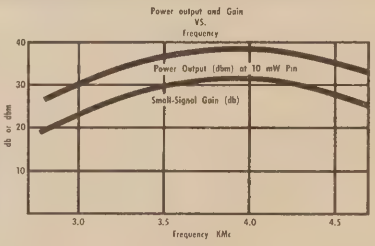


Production of traveling wave tubes at NEC began seven years ago and introduction of the package-type three years later. As chief supplier to Japan's complex network of microwave communications, NEC has become the world's largest maker of TW tubes. With the high development costs amortized and large manufacturing capacity, NEC is now able to supply these tubes at well below usual prices.

NEC's new doped nickel cathode core material, a 10-year development, increases both emission and tube life. It has been thoroughly field-proven in disc-sealed planar triodes for 2000-mc equipment of a large U.S. systems manufacturer (name on request). With its cooler operating temperature, evaporation rate of oxide is less than any other known core materials. This extends tube life up to 50%.

Designers will appreciate the compactness these tubes will give to their systems and operators the reliability and economy. Tubes connect to standard IEC waveguide flanges and can be shipped from stock.





4W76

The 4W76 operates in the 4000-mc band and has nominal saturated power output of 10 watts. High amplification over a wide range of power levels results in small-signal gain of approx. 30 db. The band width at half-power points is 1400 mc, but the tube can be used in the frequency range of 2800 to 5000 mc.

Typical Operating Characteristics at 4000 mc

First Anode Voltage	2,640 V	Saturated Power Output	12.5 watts
Helix Voltage	3,220 V	Small-Signal Gain	32 db
Helix Current	0.7 mA	Noise Figure	approx. 25 db
Collector Current	33 mA	VSWR	less than 2 to 1 (from 3500 to 4300 mc)
Focusing Electrode Voltage	–40 V		

NEC TRAVELING-WAVE AMPLIFIERS

PERMANENT MAGNET FOCUSED AMPLIFIERS

4W75	4000-mc band	1.5 watts	8W75	7000-mc band	1.5 watts
4W76	" "	5-10 watts	8W76	" "	5-10 watts
6W50	6000-mc band	5-10 watts	11W17	11000-mc band	1.0 watt

ELECTROMAGNET FOCUSED AMPLIFIERS

4W85	4000-mc band	0.1 watt	4W72A	4000-mc band	1.5 watts
4W86	" "	1.0 watt	7W52	6000-mc band	5-10 watts

Advantages of package-type

NO focusing or impedance matching at installation
NO dummy space for removal
NO power source or current stabilizer for electromagnet

NEC *Nippon Electric Company Ltd.* **Tokyo, Japan**
COMPONENTS / SYSTEMS

Give your Products

MORE RELIABILITY and BETTER PERFORMANCE with

FREED QUALITY

In stock for immediate delivery

TOROIDAL INDUCTORS

- MIL Grade 4 — Metal Case
- MIL Grade 5 — Molded
- Uncased Units
- Highest Q
- Highest self resonant freq.
- Low temperature coefficient
- No hum pickup-astatic construction
- Can be supplied with center taps

FREQUENCY RANGE: 500CP TO 15KC

Type	Max Q	Inductance Range
TI-11	290	1MH to 50Hy
TI-12	255	1MH to 30Hy
TI-1A	250	1MH to 30Hy
TI-1	210	5MH to 20Hy
TI-4	195	5MH to 5Hy
TI-5	130	5MH to 2Hy
TI-16	72	1MH to 2Hy

FREQUENCY RANGE: 10KC TO 50KC

Type	Max Q	Inductance Range
TI-13	303	1MH to 500MH
TI-2	285	1MH to 500MH
TI-6	279	1MH to 400MH
TI-7	200	.500MH to 200MH
TI-17	110	.100MH to 100MH

FREQUENCY RANGE: 30KC TO 200KC

Type	Max Q	Inductance Range
TI-18	115	.1MH to 100MH
TI-8	140	.1MH to 100MH
TI-10	185	1MH to 200MH
TI-9	175	1MH to 500MH
TI-19	100	.1MH to 5MH
TI-3	260	.1MH to 10MH
TI-3A	310	10MH to 100MH

HIGH FREQUENCY TOROIDAL INDUCTORS

FREQUENCY RANGE: 20KC TO 10MC

Type	Max Q	Inductance Range
TI-21	205	.010MH to .150MH
TI-22	250	.010MH to .700MH
TI-23	210	.010MH to .500MH
TI-20	305	.050MH to 5MH

Ruggedized,

MIL STANDARD AUDIO TRANSFORMERS

Cat. No.	Imped. level—ohms	Appl.	MIL Std.	MIL Type
MGA 1	Pri. 10,000 C.T. Sec. 90,000 Split & C.T.	Interstage	90000	TF4RX15AJ001
MGA 2	Pri. 600 Split Sec. 4, 8, 16	Matching	90001	TF4RX16AJ002
MGA 3	Pri. 600 Split Sec. 135,000 C.T.	Input	90002	TF4RX10AJ001
MGA 4	Pri. 600 Split Sec. 600 Split	Matching	90003	TF4RX16AJ001
MGA 5	Pri. 7,600 Tap @ 4,800 Sec. 600 Split	Output	90004	TF4RX13AJ001
MGA 6	Pri. 7,600 Tap @ 4,800 Sec. 4, 8, 16	Output	90005	TF4RX13AJ002
MGA 7	Pri. 15,000 C.T. Sec. 600 Split	Output	90006	TF4RX13AJ003
MGA 8	Pri. 24,000 C.T. Sec. 600 Split	Output	90007	TF4RX13AJ004
MGA 9	Pri. 60,000 C.T. Sec. 600 Split	Output	90008	TF4RX13AJ005

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Professional Group Meetings

(Continued from page 190A)

Pittsburgh—November 17

"Growth of Digital Computing Applications," J. J. Taylor, Westinghouse Electric Corp.

RELIABILITY AND QUALITY CONTROL

Columbus—December 11

"How Reliability Affects You," K. Cochran, Battelle Memorial Inst.

Columbus—December 15

"A Heretical View of Reliability," H. Braner, Battelle Memorial Inst.

"Thermoelectricity," S. Angello, Westinghouse.

Los Angeles—January 18

"The Air Force Approach to Reliability in Ballistic Missile Weapon Systems," V. J. Bracha, Air Force Ballistic Missile Div.

"Malfunction Reports and Their Requirements for Reliability," D. S. Burgess, Douglas Aircraft.

"Development of a Quality Control Program in Industry," S. Collier, Johns-Manville Corp.

New York—November 18

Organizational Meeting.

SPACE ELECTRONICS AND TELEMETRY

Detroit—January 20

"The Maser," C. Kikuchi, Univ. of Michigan.

Los Angeles—January 19

"Space Canaries for Physiological Monitoring," B. L. Ettelson, Space Labs.

San Francisco—October 1

"A Satellite Orbit Simulator," R. F. Mitchell, Western Dev. Labs.

San Francisco—October 20

"The DCS Heterodyne Telemetry System," W. D. Collins, Data-Control Systems, Inc.

"A Wide-Band Analogue Magnetic Tape Recorder," K. Thompson, Ampex Corp.

San Francisco—November 10

"The Argus Experiment," N. C. Christofilos, Lawrence Radiation Lab.

San Francisco—December 15

"A Space Communication System," J. C. Keyes, Philco Corp.

San Francisco—January 19

"The Explorer VI Experiment," C. Sonnet, Space Technology Labs., Inc.

(Continued on page 198A)

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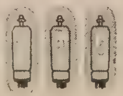

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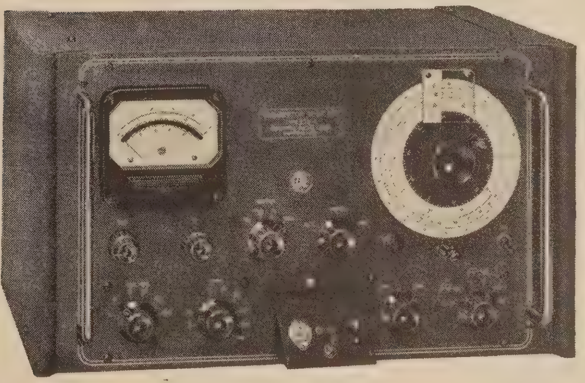
Input Resistance (h_{ib})

—with the new BRC Type 275-A Transistor Test Set



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- **Input Resistance (h_{ib})**

is presented on a large, easy-to-read dial without correction or interpolation. Two built-in, fully regulated, low ripple power supplies furnish completely variable emitter current and collector voltage.

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Alpha Measurement (h_{fb}):
RANGE: (a) 0.100 to 0.999 (b) 0.9001 to 0.9999
ACCURACY: (a) $\pm\ (0.1 + \frac{0.09}{h_{fb}})$ %* (b) ± 0.2%*
*when $f_\alpha \geq 500$ Kc.

Beta Measurement (h_{fe}):
RANGE: 7 to 200
ACCURACY: $\pm\ (0.6 + \frac{30}{h_{fe}})$ %*
*when $f_\alpha \geq 500$ Kc.

Input Resistance Measurement (h_{ib}):
RANGE: (a) 0.30 to 30 ohms (b) 3.0 to 300 ohms
(c) 30.0 to 3000 ohms
ACCURACY: (a) ± 3%* (b) ± 3%* above 30 ohms
(c) ± 3%*
* for linear impedances

Collector Voltage Supply:
RANGES: Internal: 0 to 100 V.D.C.
External: 0 to 100 V.D.C.
METERING: Range: 0 to 2, 5, 10, 20, 50, 100 volts
Accuracy: ± 1.5% full scale

Emitter Current Supply:
RANGE: Internal: 0 to 100 ma D.C.
External: 0 to 5 amp. D.C.*
*h_{fb} only; $I_b \geq 100$ ma D.C.
I_E and I_C metered externally
METERING: Ranges: 0 to 0.1, 0.2, 0.5, 1, 2, 5,
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Accuracy: ± 1.5% full scale

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- Special test circuit guards against transistor burnout

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DIMENSIONS: 1-⅞" x 1½" x 4⅜ H. Weight: 6¼ Ounces.

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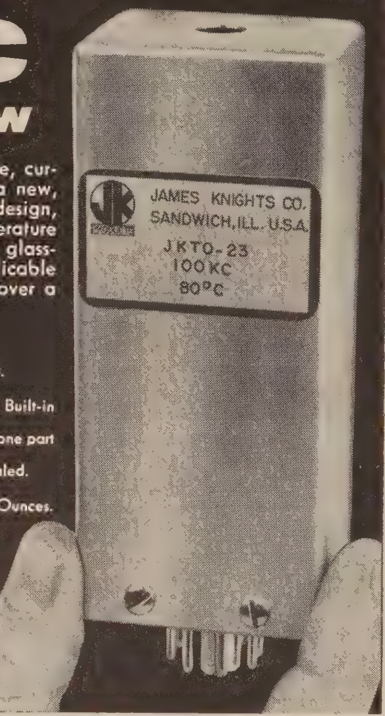

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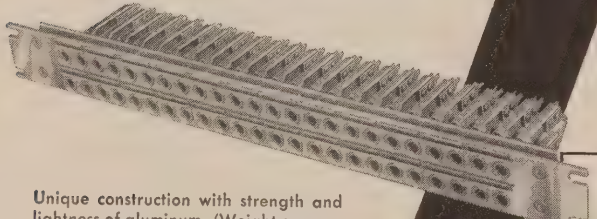

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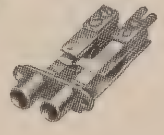

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Professional Group Meetings

(Continued from page 196A)

San Francisco—February 16

"Design Considerations for a PAM-FM Telemetry System," T. D. Lusk, Lockheed Missiles and Space Div.

VEHICULAR COMMUNICATIONS

New York—December 9

"Electronic Control of Automobiles," L. E. Flory, RCA Labs.

Washington—January 27

"Mobile Radio Maintenance Seminar," I. K. Redd, Mobile Communications; W. Switzer, Radio Communication Service; E. Williams, District of Columbia Govt.

IRE People

(Continued from page 85A)

William W. Lawrence, Jr. (M'57) has been promoted to advisory engineer in the Memory and Magnetics Engineering Department of the IBM Poughkeepsie Product Development Laboratory. He is engaged in high speed memory development using advanced semiconductor devices.

He joined IBM as a customer engineer at Boston in 1950. He came to Poughkeepsie in 1952 for work on magnetic cores in the Component Research Department and in 1953, engaged in work on the first magnetic core buffers on input-output equipment for the IBM 702 Computer. He became an associate engineer, assigned to the design of a matrix switch drive system for the IBM 704 and 705, in 1955, and was promoted to project engineer in March, 1956, in charge of a group working on high-speed core memory systems.

Mr. Lawrence received the B.A. degree from Amherst College, Amherst, Mass., and in 1948, the B.S.E.E. degree from Massachusetts Institute of Technology, Cambridge, in 1950.

⁂

John R. Lyon (M'57) has been promoted to the position of development engineer in Systems Components Engineering at the IBM Poughkeepsie Product Development Laboratory. He has responsibility for adaption of a standard disk file to all Data Systems Division computers, as well as the development of a disk synchronizer and high speed exchange for two advanced data systems.

He joined IBM in 1941 as a customer engineer. He became a technical engineer engaged in design and test of the IBM 704 in 1954 and has subsequently held positions as associate engineer, project engi-

(Continued on page 202A)

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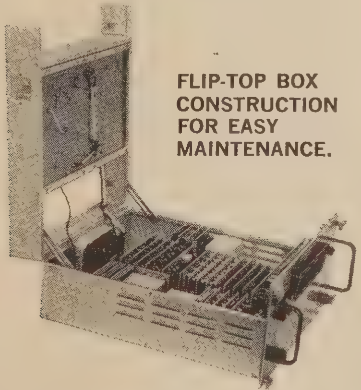

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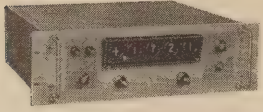

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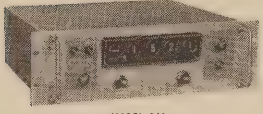
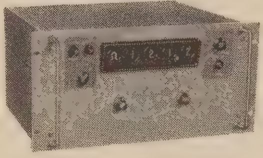
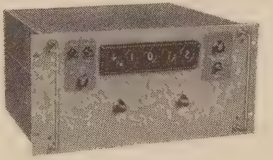


MODEL 841
DC Volts/DC Ratios/Resistance

MODEL 842
DC Volts/DC Ratios/AC Volts



MODEL 843
DC Volts/DC Ratio/AC Volts/Resistance



MODEL 844
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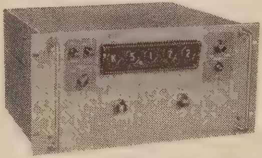

MODEL 845
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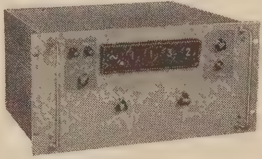

MODEL 846
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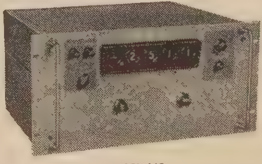
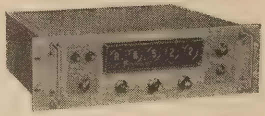


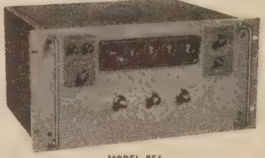
MODEL 847
DC Volts/Ratio/AC Volts/Resistance/Pre-Amplifier



MODEL 848
DC Volts/Ratio With Electrical Outputs

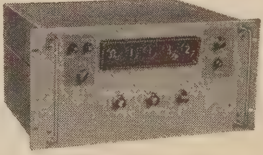
MODEL 849
DC Volts/DC Ratios/Resistance
With Electrical Outputs

MODEL 850
DC Volts/DC Ratios/AC Volts
With Electrical Outputs



MODEL 851
DC Volts/DC Ratio/AC Volts/Resistance
With Electrical Outputs

MODEL 852
DC Volts/Ratio/DC Pre-Amplifier
With Electrical Outputs



MODEL 853
DC Volts/Ratio/Resistance/DC Pre-Amplifier
With Electrical Output

MODEL 854
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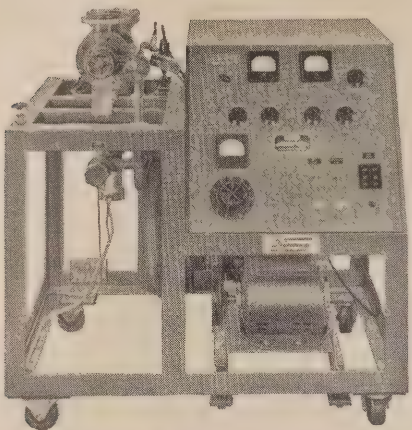

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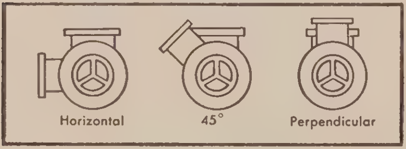

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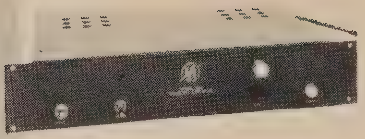
Wide Band Amplifier Model 530



GENERAL DESCRIPTION

The Model 530 Wide Band Amplifier has been designed to fill a need for an amplifier used principally for voltage amplification of CW or pulsed signals.

This model has many applications in the laboratory and also for television distribution systems. It may be used to increase the output from signal sources within its frequency range, and its bandwidth of 300 mc's makes it ideal for amplifying millimicrosecond pulses.

PRICE $330.

SPECIFICATIONS

Bandpass	10 KC to 300 MC
Voltage Gain	18 db
Input Impedance	135 ohms
Output Impedance	150 ohms
Max. Output Power (into Matched Load)	.08W
Max Output Voltage (into Matched Load)	3.5 Vrms
Max. Peak Pluse Output	7 V pos. or neg.
Rise Time	Less than 2x10⁹ sec
Dimensions	19" front panel—16" wide, 9" deep 3½ high. Power supply included.
Gain Control	Provided on front panel
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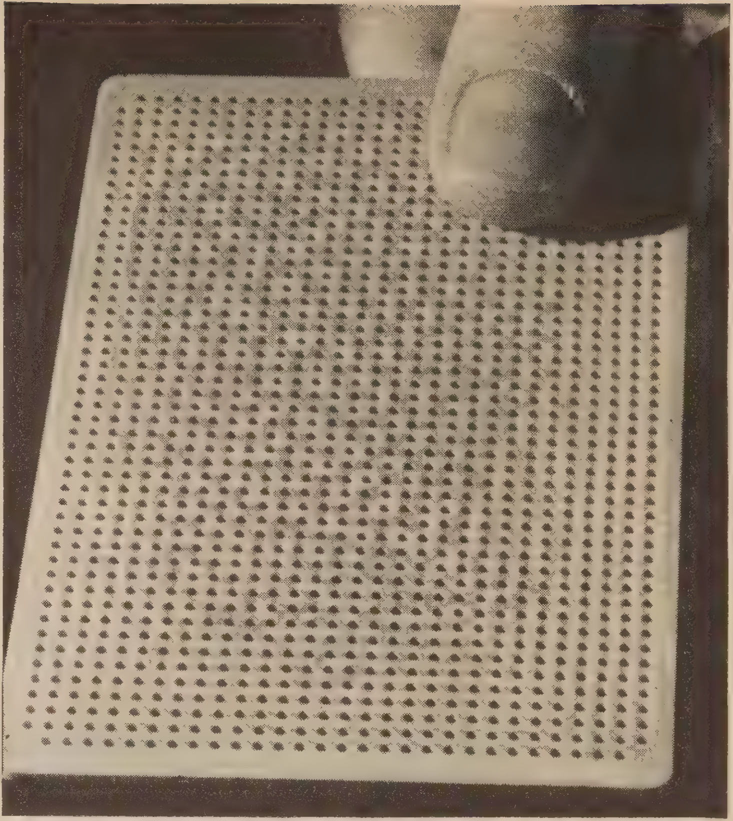
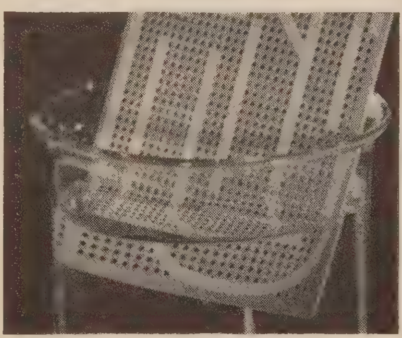
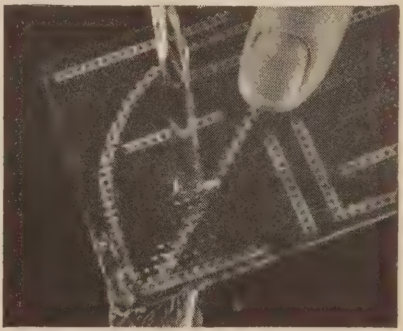


1. New Corning grid boards are already holed and coppered to give you maximum design flexibility.

2. Lay out the circuit run you want on one or both sides with tape or chemical resist.



3. Immerse in a copper etchant to remove excess copper.



4. Rinse. That's all there is to making a board ready for use.

Take a new Corning Fotoceram copper-plated grid board. Apply a tape or chemical resist of your circuit pattern. Etch away the excess copper. Rinse the board, and strip the resist. You're ready to add components.

No adhesives are used. The board has 0.052 inch holes spaced 0.1 inch apart on centers. The holes, too, are already plated.

The base is Fotoceram, a glass-ceramic, a proved production material that's used widely in printed circuits which demand high strength, temperature resistance to 250°C., zero moisture absorption, nonflammability, and rigid dimensional stability.

Excellent through-hole plating. Hole plating is done with the same material used for circuit-run conductors. This provides exceptional thermal and electrical conductivity and negates the need for eyelets.

We have soldered, removed, and resoldered components to these boards as many as fifty times without circuit-run failure.

No bending, bowing, delaminating. The Fotoceram base is a solid piece. There are no laminations which might bend, twist, or warp under high temperatures.

Three sizes. There are currently three boards, all 1/16″ thick: 3″ x 5″, 6″ x 8″, 9″ x 12″. They can be trimmed to any shape with a simple glass cutter.

Small production runs. Some of our customers are using these boards for small production runs as well as R&D work.

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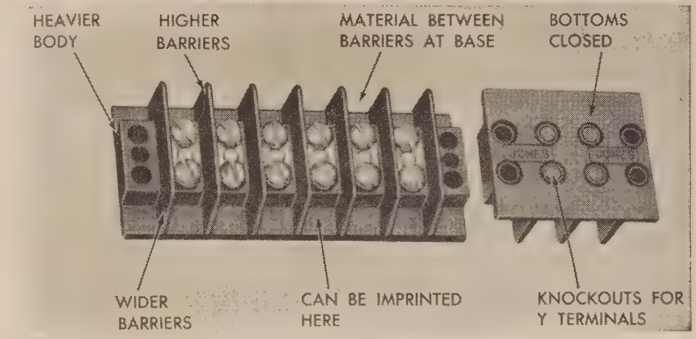

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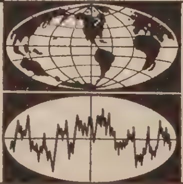

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(Continued from page 198A)

neer and staff engineer, engaged in design and development of the IBM 704 and another advanced system.

He received the B.S.E.E. degree from the University of California in 1941, is a veteran of the U. S. Navy, and presently a Lt. Commander in the U. S. Naval Reserve. Mr. Lyon is a member of Eta Kappa Nu.

❖

The appointment of **Dr. Robert Malm** (SM'56) as a senior engineering specialist at the Amherst Engineering Laboratory of Sylvania Electric Products Inc. has been announced by Dr. Robert L. San Soucie, manager of the advanced communication systems department. Sylvania is a subsidiary of General Telephone & Electronics Corporation.

The Amherst Engineering Laboratory is a facility of the Buffalo Operations of Sylvania Electronic Systems, a division of the company. Affiliated with Sylvania Electronic Systems since 1957, Dr. Malm is responsible for communications physics at the Amherst laboratory.

He received the B.S. degree in electrical engineering from the University of Minnesota, Minneapolis, and the Ph.D. degree in physics from Massachusetts Institute of Technology, Cambridge. Prior to joining Sylvania, he served as an associ-

(Continued on page 207A)

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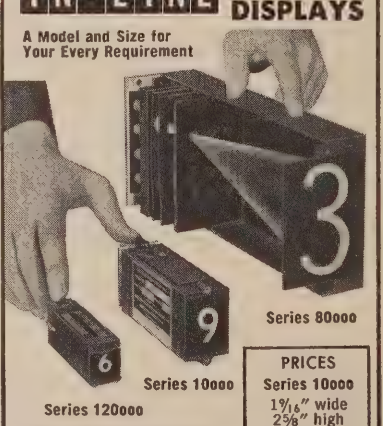

PRICES
Series 10000
1$\frac{9}{16}$" wide
2$\frac{5}{8}$" high
5$\frac{5}{8}$" long
$18.00 each
Series 80000
3$\frac{1}{4}$" wide
5$\frac{1}{4}$" high
11$\frac{15}{16}$" long
$33.00 each
Series 120000
1" wide
1$\frac{5}{16}$" high
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$35.00 each
Quantity Prices On Request

OUTSTANDING FEATURES
- All digits displayed on front viewing screen
- All digits uniform in size and intensity
- High-contrast viewing screen
- Digit style of your choice
- Colored digits of your choice
- Individual units may be group assembled for panel mounting

WRITE TODAY FOR COMPLETE SPECIFICATIONS
Representatives in principal cities

INDUSTRIAL ELECTRONIC ENGINEERS, Inc.
IEE
5528 Vineland Avenue,
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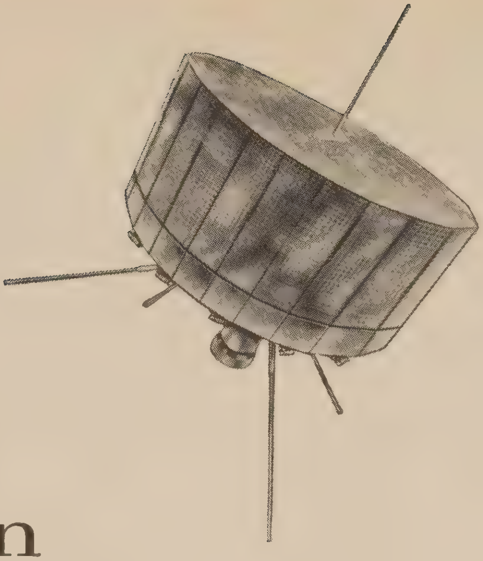
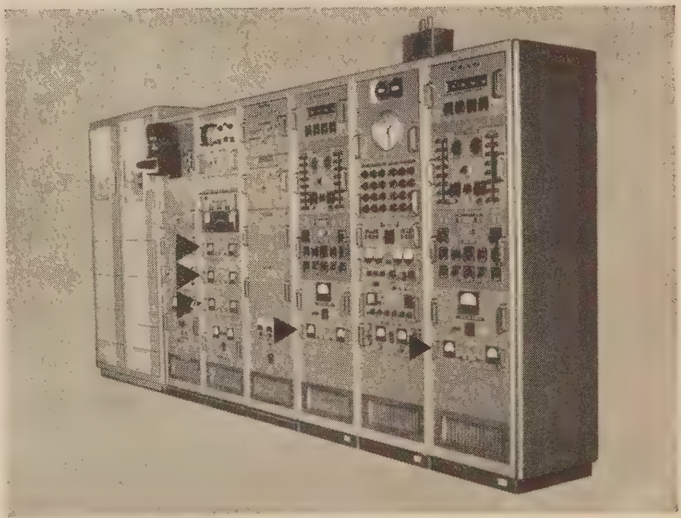


TIROS relies on LAMBDA reliability

Standard Lambda Regulated Power Supplies have again been selected for a job where reliability and quality are of vital importance. They power the ground equipment in the primary and back-up stations that control and track America's newest missile—TIROS.

In TIROS as in SAGE, Digital Computer Intervention and Display System and other leading electronic projects, Lambda Power Supplies are specified because Lambda equipment has consistently proven its reliability.

This same Lambda quality is the reason Lambda Power Supplies are consistently selected *first* by engineers in independent surveys. To find out more about Lambda Supplies, which are guaranteed for a full five years, send today for the Lambda Catalog. It gives data on Lambda's complete line of tube models ranging up to 525 VDC and transistor models up to 10 Amps.



The Tiros System

Sponsored: National Aeronautics and Space Administration
Technical Direction: U. S. Army Signal Research and Development Laboratory
Developed and Built: Astro- Electronic Products Division, Radio Corporation of America

LA104

LAMBDA ELECTRONICS CORP.
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NEED MORE THAN FOUR?

Only Voltmeter with the Factual Fifth Figure

WHEN FOUR-DIGIT ACCURACY JUST ISN'T ENOUGH, specify the five-digit NLS V35 — world's most accurate digital voltmeter. Only the V35 gives you the "factual fifth figure" . . . full five-digit resolution of 0.001%. Here is the instrument for your measuring jobs demanding maximum accuracy — automatic missile checkout, readout and printout in data logging and computer systems, critical production inspection. Only the V35 offers you the benefits of "no-needless-nines" logic — greater reliability, increased speed, longer parts life. Contact NLS today for the full story.

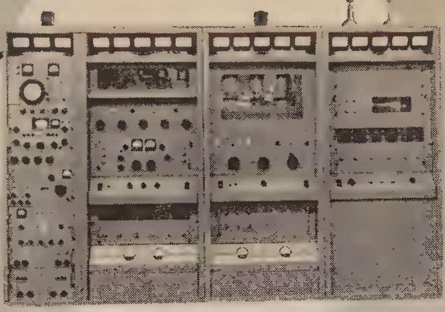
V35 Specifications: Measures DC voltage from ±0.0001 to ±999.99; DC voltage ratio from ±00.001% to ±99.999% . . . DC voltage accuracy is ±0.01% of reading or ±1 digit . . . overall accuracy for voltage ratio is ±0.005% of reading or ±1 digit . . . "factual fifth figure" — 0.001% resolution . . . transistorized "no-needless-nines" logic . . . plug-in modular construction . . . simple external connections for AC/DC converter, pre-amplifier and data logging accessories . . . one-package design — 5¼" high — for standard rack mount . . . automatic selection and indication of range and polarity . . . interchangeable plug-in stepping switch-resistor assemblies sealed in oil . . . $3,750.00, complete. Available in four-digit model for $3,150.00, complete.

NLS *Originator of the Digital Voltmeter*

non-linear systems, inc.
DEL MAR (SAN DIEGO), CALIFORNIA

GPT-40K **AN/FRT-40**

- 4 to 28mc.
- 40,000 watts PEP
- ALDC
- Filtered air cooling
- Semi-pressurized cabinet
- Safety interlocks throughout



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40,000 WATTS

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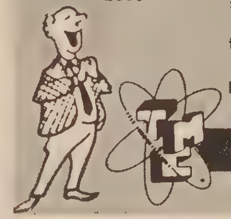

The TMC transmitter, Model GPT-40K, is a completely self contained unit including all power supplies and ventilating equipment. All components are housed in four modular assemblies occupying only 40 square feet of floor space.

The transmitter includes equipment for immediate monitoring and testing of all vital operating points.

To provide for complete flexibility in operation, 1 Kw or 10 Kw outputs are readily available for reduced power or emergency operation.

The unit is available with or without synthesizer control.

THE TECHNICAL MATERIEL CORP.
MAMARONECK, NEW YORK

CABLE RETRACTOR INSTALLED
One support rail is shown cut away to more clearly illustrate complete absence of cable sag at every stage.
TOP—installation with slide closed
MIDDLE—chassis partly withdrawn
BOTTOM—slide extended, chassis tilted

PREVENTS ENTANGLING COMPONENTS

CABLE RETRACTOR

Withdrawal of a chassis for service and its return to position no longer presents the old bugaboo of cable entanglement with and damage to tubes and components in the chassis immediately below it.

This new cable retractor's double action maintains a constant tension and correct suspension of cable at all times—permits adequate cable length for full extension and tilting of chassis without hazard of snagging.

May be used with all types of chassis or drawer slides, is adjustable to fit varying chassis lengths, is simple to install, and has proven thoroughly reliable in operation.

Mounts on rear support rails on standard 1¾" hole increments. Cadmium plated cold rolled steel.

Write for complete data

ONE SOURCE... for VENTILATED RELAY RACK CABINETS, CONTROL CONSOLES, BLOWERS, CHASSIS, 'CHASSIS-TRAK'*, RELATED COMPONENTS

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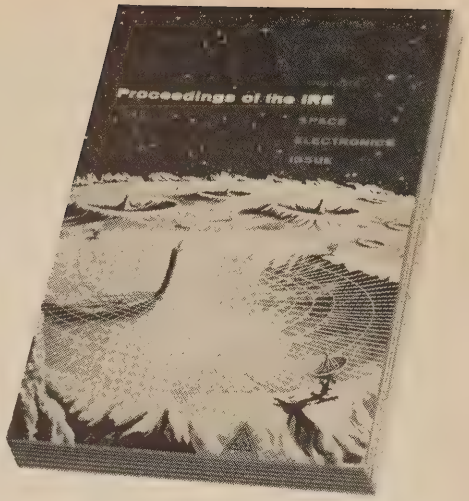
VITAL NERVE CENTER OF MAN'S EXPLORATION OF THE UNIVERSE!



Man's escape from the confines of his planet offers him revolutionary opportunities for performing whole new ranges of scientific experiments, notably in such fields as astronomy, physics and geophysics. Electronics, because it provides the vital nerve system for such experiments, will be at the very center of these new exploits in space. Moreover, earth satellites, possibly in a 24-hour equatorial orbit, promise to open a new era in global communications in which almost limitless bandwidths may become available at relatively low cost.

Comprehensive Report On The Present And Future Role of Electronics In Space Exploits

In this important special issue are articles on propulsion, navigation and guidance, communication, tracking and surveillance, telemetry and instrumentation and measurements. There are over 50 of these studies, each one contributing to the radio-engineers' interest in space — for performing new scientific experiments, global communications and space travel.

This Space Electronics issue is another in the many services offered members of the IRE. Non-members of the Institute of Radio Engineers, however, are invited to reserve a copy of this vital report by returning the coupon below, today.

PARTIAL CONTENTS OF THIS APRIL SPACE ELECTRONICS ISSUE:

"The NASA Space Science Program"

"A Comparison of Chemical and Electric Propulsion Systems for Interplanetary Travel," by C. Salzer, R. T. Craig and C. W. Fetheroff

"Photon Propelled Space-Vehicles," by D. C. Hock, F. N. McMillan, and A. R. Tanguay, Radiation, Inc.

"Interplanetary Navigation," by G. M. Clemence, USN Observatory

"Navigation Using Signals from High Altitude Satellites," by A. B. Moody, USN Hydrographic Office

"Inertial Guidance Limitations Imposed by Fluctuation in Gyroscopes," by G. C. Newton, Jr., MIT

"Propagation and Communications Problems in Space," by J. H. Vogelman, Dynamic Electronics-New York, Inc.

"Communication Satellites," by D. L. Jacoby, U. S. Army Signal Research & Development Lab.

"Interference and Channel Allocation Problems Associated with Orbiting Satellite Communication Relays," by F. E. Bond, C. R. Cahn and H. F. Meyer, Ramo-Wooldridge

"Solar Batteries," by A. I. Daniel, USASRDL

"Extra-Terrestrial Radio Tracking and Communication," by M. H. Brockman, H. R. Buchanan, R. L. Choate and L. R. Malling, NASA-California Institute of Tech.

"Tracking and Display of Earth Satellites," by F. F. Slack and A. A. Sandberg, AF Cambridge Research Center

"Interplanetary Telemetering," by R. H. Dimond, Radiation, Inc.

"The Telemetry and Communication Problem of Re-Entrant Space Vehicles," by E. F. Dirsa, Admiral Corp.

"Radiation and Instrumentation Electronics for the Pioneer III and IV Space Probes," by C. Josias, California Institute of Technology

"Applications of Doppler Measurements to Problems in Relativity, Space Probe Tracking and Geodesy," by R. R. Newton, The Johns Hopkins University

"High Speed Electrometers for Rocket and Satellite Experiments," by J. Praglin and W. A. Nichols, Keithley Instruments, Inc.

THE INSTITUTE OF RADIO ENGINEERS
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Enclosed is $3.00

Enclosed is company purchase order for the April, 1960, issue on Space Electronics.

All IRE members will receive this April issue as usual. Extra copies to members, $1.25 each (only one to a member).

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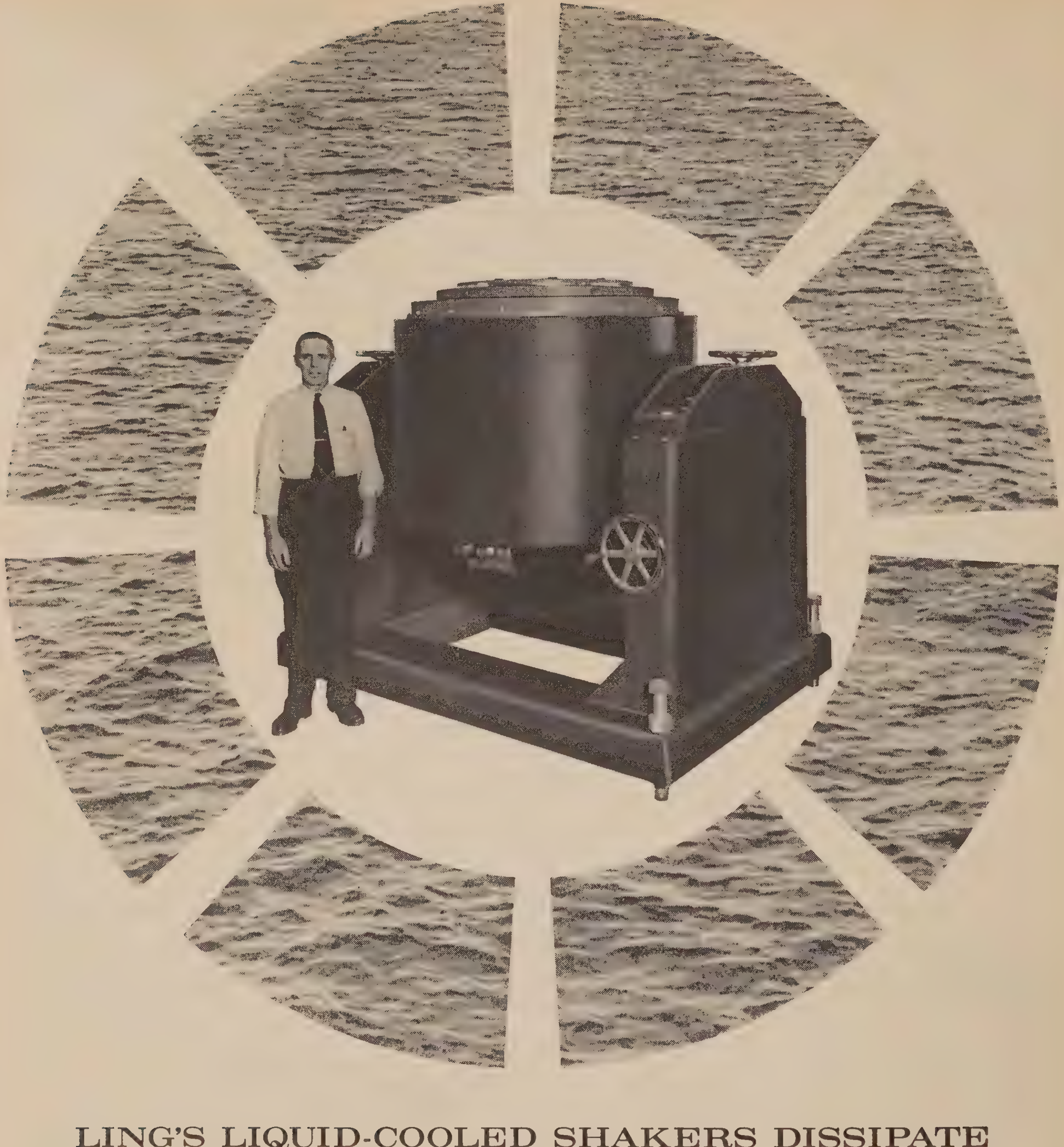


LING'S LIQUID-COOLED SHAKERS DISSIPATE HEAT FAST WITH WATER

Improved system efficiency goes with the improved design of Ling's new series of liquid-cooled shakers. For instance, Model 249 shown above not only offers an impressive 28,000 pound force rating, but a number of other advantages. The new closed-loop cooling system, employing clean raw or distilled water, dissipates heat so efficiently that less is dumped on the testing site. The series also features a new web-design armature of lightweight aluminum. Force is transmitted to the table with maximum rigidity. Finally, special construction details make these liquid-cooled shakers adaptable for environmental chamber testing without special accessories. Tests can be conducted from −100°F to 300°F at any altitude. Field and armature coils are designed to help eliminate corona at altitudes; special thermal barriers can be supplied which control heat flow from the shaker to the chamber. This built-in adaptability and high efficiency grow from Ling research; For details on the liquid-cooled shaker series, write to IRE-2. at either address below.

LING
ELECTRONICS

A DIVISION OF LING-ALTEC ELECTRONICS, INC. • 1515 SOUTH MANCHESTER, ANAHEIM, CALIFORNIA • 120 CROSS STREET, WINCHESTER, MASSACHUSETTS

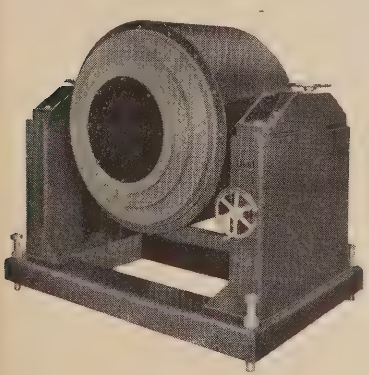
LING ELECTRONICS

The shaker at the left is just one of many design improvements to grow out of Ling's continued research and development program. Its high 28,000 pound force rating—one of the highest force ratings available—is another result of Ling's constant search for better equipment and better methods of vibration testing.

In addition to the special advantages offered by the efficient liquid-cooling system, this new series offers other important features which it has in common with the air-cooled shaker series.

Ling's dual magnetic field structure provides a low stray field and improved force-current linearity. Ling shakers are engineered to operate continuously at maximum force on low input, feature simplified compensation over wide bandwidths.

Check the ratings on the entire liquid-cooled series. The performance of the series is just one more proof that whatever your needs in high power electronics — vibration testing, acoustics or sonar—you can rely on Ling for the most advanced design and practical engineering.



LING'S LIQUID-COOLED SHAKERS cover this useful range of force ratings:
Model 245—2,000 lb. force rating
Model A246—7,500 lb. force rating
Model 275—10,000 lb. force rating
Model 249—28,000 lb. force rating

LING
ELECTRONICS

HIGH-POWER ELECTRONICS FOR
VIBRATION TESTING • ACOUSTICS • SONAR

IRE People

(Continued from page 202A)

ate physicist at the Argonne National Laboratory and as a member of the technical staff of the Bell Telephone Laboratories.

Dr. Malm is the author of numerous technical papers. He is a member of the American Physical Society, The Association for the Advancement of Science and several other professional groups on antennas and propagation, information theory, communication systems and engineering management.

⁂

Electro-Mechanical Research, Inc., Sarasota, Fla., has established a new Sales District Office in Huntsville, Ala.

P. T. Miller

The new office will be managed by **Peter T. Miller** (M'55) who will represent the military telemetering components of both EMR and ASCOP division of EMR in the Huntsville area. He has had previous experience in electronics engineering with electronics companies, and in the TV and radio broadcasting industries. Before joining Electro-Mechanical Research, Inc., he was associated with the Chrysler Missile Division as Managing Engineer of Instrumentation stationed at Redstone Arsenal in Huntsville. He is Program Chairman of the Huntsville Section of the IRE.

As of April 1st the office address will be Suite 21, Holiday Office Center, So. Memorial Pkwy., Huntsville, Alabama.

⁂

Milton E. Mohr (M'45–SM'53) has been appointed vice president, operations, and **Bernard Berman** (M'55) was named director, special projects for Ramo-Wooldridge, a division of Thompson Ramo Wooldridge Inc.

In his newly created post, effective immediately, Mr. Mohr will have responsibility for over-all direction of operations of the Ramo-Wooldridge Division located at the Ramo-Wooldridge Laboratories, Canoga Park, California. He was formerly vice president of engineering of the Ramo-Wooldridge Division.

Mr. Berman, as director of special projects, will be responsible for initial development of new areas of application for Ramo-Wooldridge systems, techniques and equipment.

Mr. Mohr joined Ramo-Wooldridge in 1954, with 22 years' experience in research and development of communication circuits and systems, and technical administration.

Prior to joining R-W, he was a department head in the radar laboratory of Hughes Aircraft Company where, for four

(Continued on page 208A)

a tradition in voltage regulated dc power supplies

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the standard for the "state of the art" for over 14 years

More than 120 standard active models
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transistorized
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For complete specifications send for Catalog B-601.

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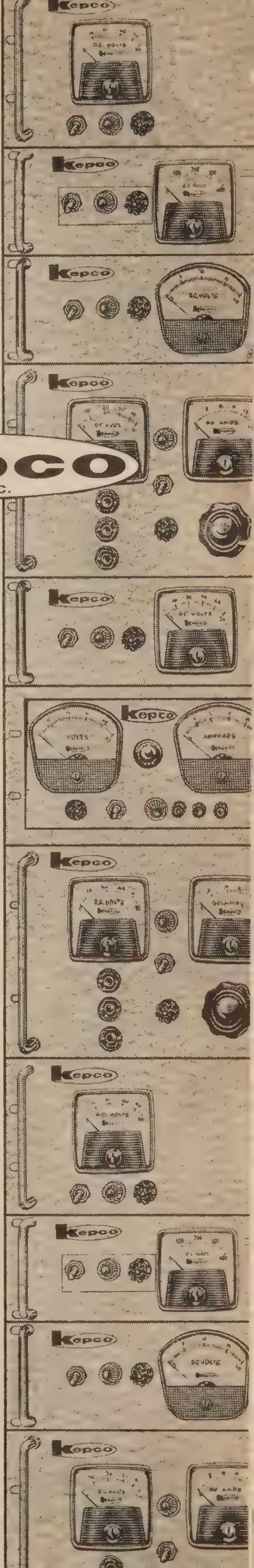

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TOP HATS
for
everyone!

Protect electron tubes, relays, capacitors, other plug-in components for equipment reliability.

These superior retainers now come in a variety of sizes and styles to fit nearly every plug-in component.

Positive — Top Hat® retainers hold components securely in any position . . . can't shake loose even when upside down.

Corrosion Resistant — Both hats and posts are of stainless steel for maximum reliability. Materials and finishes comply with all Military Specifications.

Resilient — Special spring action gives positive retention yet preserves desired flexibility and prevents strain on component.

Easy on, easy off — Simple finger pressure fastens or releases clamp —no tools to slip or waste time—no tiny parts to lose.

Top Hats clamp any components. If you have special requirements, write Dept. E for quotations.

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IRE People

(Continued from page 207A)

years, he contributed to the development of advanced interceptor fire control systems. From 1938 to 1950, he was a member of the technical staff of the Bell Telephone Laboratories.

He has the B.S. degree in Electrical Engineering from the University of Nebraska, as well as an honorary doctorate of engineering from that school. He is the author of several technical papers and the holder of twenty-two patents.

Mr. Mohr is a member of the American Institute of Electrical Engineers, the New York Academy of Sciences, and the American Rocket Society. He is also a member of Sigma Tau, Sigma Xi, Eta Kappa Nu and Pi Mu Epsilon.

Mr. Berman joined R-W in 1954 with ten years' experience in design, development and flight test of airborne electronic systems. Prior to joining R-W, he directed flight test of E-series fire control systems, and development of techniques to achieve quantitative flight test data for a local aircraft company.

He has the B.S. and M.S. degrees in physics from the University of Minnesota, and is a member of Phi Beta Kappa and the American Physical Society.

⁂

(Continued on page 210A)

For the highest
RELIABILITY IN PRECISION COMPONENTS

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For basic research, pilot plant studies and production of semiconductors

LINDBERG GASEOUS AND SOLID DIFFUSION FURNACES

LINDBERG
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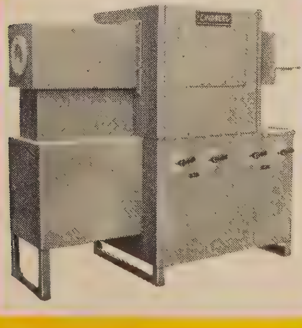
These Lindberg four-tube furnaces at Microwave Associates, Inc., provide maximum continuous operating temperature to 1371°C. (2500°F.). Chamber accommodates four 2″ O.D. and has a uniformity of plus or minus 5.0°C.

Microwave Associates, Inc., Burlington, Mass.; a leader in the development of specialized semiconductor products, must give careful consideration to the choice of technical equipment to assure maintaining their position in this highly competitive field. Consequently, the Microwave installation shown above was selected from Lindberg's complete line of gaseous and solid diffusion furnaces for quality transistor and semiconductor devices. This line provides a wide variety of standard sizes and capacities to enable manufacturers in the semiconductor field to have higher powered equipment adequately insulated and designed for its specific use. Models available in single and multiple zone types and a variety of tube sizes up to 4″ I.D. These Lindberg furnaces are versatile, perfectly adaptable for basic research, pilot plant study and production.



LINDBERG SOLID DIFFUSION FURNACE: Preheat chamber 21″ long with two zones of control—maximum temperature 900°C. (1652°F.). High heat chamber 16″ long with two zones of control, maximum operating temperature 1300°C. (2372°F.).

For full information call your local Lindberg Field Representative (see your classified phone book) or write for Bulletin No. 1081.

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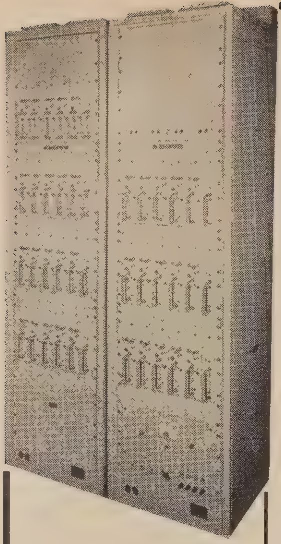

AFFT MODEL—804
SPECIFICATIONS

INPUT FREQUENCY RANGE: Signals from 150 cps to 5000 cps

OUTPUT FREQUENCY RANGE: 10 cps to 150 cps flat to within 3 db for each channel unit

UNDESIRED FREQUENCY REJECTION: Greater than 50 db.

SIGNAL INPUT LEVEL: Wideband noise at a maximum level of zero dbv — — 50 dbv dynamic range

A NEW APPROACH TO . . .

SOUND SPECTRUM ANALYSIS

Through this . . .

ACTIVE FILTER FREQUENCY TRANSLATOR

Rixon's Active Filter Frequency Translator (AFFT) provides a solution to sound spectrum analysis requiring rapid and very detailed audio spectrum examination. The photo shows 35 independent channel units each capable of extracting any 150 cps wide portion from a broad spectrum (0 to 5 KC) and translating that portion to a new location for further processing by secondary analyzer equipment. The process is a first-time application of a "quadrature function" technique which filters while it translates and insures high rejection of undesired frequencies.

AFFT's applications in new areas of sound spectrum analysis are of as much interest to Rixon as they are to you. Write for Rixon Engineering Bulletin #67 to learn more about AFFT, and then, let's talk about your application.

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Offers to Case Stand 358, Geneva, Switzerland.

IRE People

(Continued from page 208A)

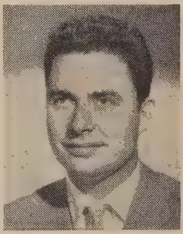
K. C. Moritz

Appointment of **Kenneth C. Moritz** (M'53–SM'58) to the newly-created post of Vice President-Marketing of General Instrument Corporation's Semiconductor Division, has been announced by Maurice Friedman, Vice President and General Manager of the Division. Previously National Sales Manager for the Raytheon Company's Semiconductor Division, Mr. Moritz will be in charge of all semiconductor sales, marketing and advertising activities for General Instrument, directly under Mr. Friedman. He will make his office at the Company's Newark, N. J., headquarters plant.

Prior to his employment with Raytheon, he had been with Philco Corporation for 12 years in various government and industrial executive sales capacities, including Philco's European operations. He previously was an officer in the Signal Corps.

A graduate of New York University, Mr. Moritz did graduate work at George Washington University; he is a member of the American Management Association and the National Sales Executive Club.

❖



R. W. Murray

Homer R. Denius, President of Radiation Incorporated, has announced the appointment of **Roy W. Murray, Jr.** (M'51) as Eastern Director of Marketing.

Prior to joining Radiation, he was Western Regional Manager for Tele-Dynamics, Inc., and TDI'S resident engineer for customer indoctrination and engineering liaison.

Mr. Murray is a graduate of Dartmouth College with the B.A. degree in Electrical Engineering. He was past Program Chairman, Secretary and Chairman of the Los Angeles Chapter, IRE Professional Group on Space Electronics and Telemetry. Other memberships include the American Rocket Society and ISA.

❖

Robert C. Paulsen (M'59) has been advanced to the position of advisory engineer at the IBM Poughkeepsie Product Development Laboratory. In his position, he is engaged in functional unit development in the Systems Engineering Department of Advanced Computational Systems.

He attended Newark College of Engineering, Newark, N. J., and joined IBM

(Continued on page 212A)

NEW INSTRUMENTS

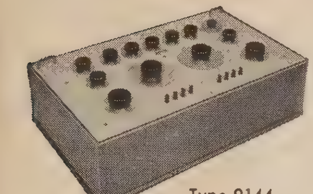
by Sensitive Research

RF VOLTMETER CALIBRATOR

Model RFVC

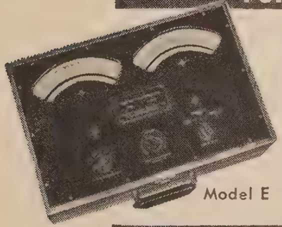
Model RFVC — Radio Frequency Self Checking RMS voltmeter for the certification of VTVM's from DC to 10 Mc. Accuracy .3% of full scale ± .2% frequency influence. Ranges .01/.1/1/3 V. Checks its own accuracy against a .05% stable internal standard source.

DC POTENTIOMETERS


Type 9144

A new line of 6 figure instruments guaranteed 10X more accurate than any potentiometer commercially available today, having a subdivision of 1 part in 10^6 of the 1 volt setting and calibrated to be usable to an accuracy of ± .0002% or better. Absolute accuracy guaranteed to ± .001% nominal or better. Resolution excellent for comparison of saturated standard cells. Temperature controlled. High sensitivity Galvanometer, 4 terminal NBS Type resistors, ratio boxes and other primary standards available.

FORM FACTOR INSTRUMENT


Model E

Model E — supplies a direct reading correction factor for instruments affected by non-sinusoidal wave form deviation. Indicates ratio of true RMS values to average, positive peak, and negative peak values. Determines the true RMS values of average and peak reading instruments that are used on a distorted wave. Accuracy: .2% between 25-500 cps.

GENERAL PURPOSE PORTABLES

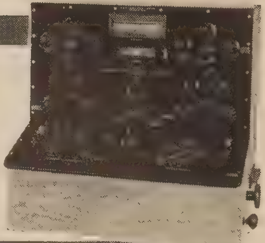
Model N

Model N—economically priced, stable and rugged .5% accurate DC current and voltage instrument. Long 6.1″ scale. Employs a shielded "U" shaped magnet and not the common center core type characteristic of instruments in its price range. Model NP is for panel mounting. Model NSI is an AC version. All have molded bakelite cases and are available switch controlled.

Primary and secondary standards for the accurate measurement or certification of AC-DC current, voltage, power, power factor, frequency and magnetic quantities. All electrical indicating instruments have hand-drawn mirrored scales and most are Diamond Pivoted, of course!

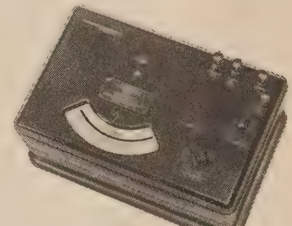
Not illustrated above, but available, are a complete line of portable and panel types including: **• Wattmeters • Electrostatic Voltmeters • Peak Voltmeters • Thermocouple Instruments • Differentials • Ratiometers • Corrosion Instruments • Panel Instruments • Test Sets • Fluxmeters and accessories such as Shunts and Multipliers.** All SRIC instruments have their certification directly traceable to the National Bureau of Standards and are unconditionally guaranteed.

CALIBRATION CONSOLES


Model LTC

Model LTC — AC-DC/DC. Accuracy .05% of actual reading. Ranges .5 V. to 1111 V.; 1 Ma (2 Ma on AC) to 11.11 amps. Resolution .01%. Frequency range DC to 25 KC. Direct % Error Readout. Model LT-PS — AC power supply to full capabilities of console. Harmonic distortion less than .1%. Other consoles available.

EXPANDED SCALE INSTRUMENTS


Model INCRE

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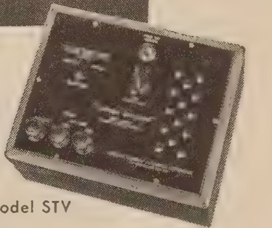
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Antenna Laboratory: Smithtown, N. Y.

IRE People

(Continued from page 210A)

in 1940 at World Headquarters as a technician. He was a customer engineer and later, field supervisor at various locations until 1944, when he want on military leave of absence. Rejoining IBM in 1946, he became an associate engineer in the WHQ Patent Development Department, serving there until 1953 when he transferred to Watson Laboratory. He came to Poughkeepsie attached to the Research Center in 1955 and assumed his present assignment on an advanced data system in 1958.

❖

United Aircraft Corporation's Norden division has announced the promotion of **Frank S. Preston** (M'48–SM'55) to chief engineer, **Edward R. Harris** (M'52) to assistant chief engineer, and **Leo Botwin** (SM'54) to chief-engineering operations.

Mr. Preston has been associate technical director of the division's Norden Laboratories department in White Plains since 1956. He joined Norden in 1945 as an engineer and successively became project and systems manager and assistant director of engineering.

A native of Iowa City, Iowa, he received the B.S. degree in electrical engineering at the University of Washington in 1940 and later the M.S. degree at Massachusetts Institute of Technology.

He holds membership in the Association of Computing Machinery. He was an organizer of the Westchester branch of the IRE and served as its chairman in 1956. He also is a member of the Anti-Submarine Warfare Committee, National Security Industrial Agency.

Mr. Harris has been assistant technical director of Norden Laboratories. He joined the Laboratories project staff in 1953 and later became head of the television department where he directed the development of stabilized and unstabilized airborne television viewfinders.

He was born in Toms River, N. J., and received the B.S. degree in electrical engineering at Massachusetts Institute of Technology in 1940. He has made substantial contributions to hydraulic power flight control systems, including the development of the first longitudinal rate damping system.

Mr. Botwin has been assistant manager of engineering operations of the Laboratories since September, 1958. He joined the organization in 1956 and his assignments included that of project manager for the company's nose cone attitude control system program.

He received the B.S. degree (cum laude) in electrical engineering from City College of New York in 1943. He enlisted in the Army and was assigned to the National Advisory Committee for Aeronautics. Following the war he became a research fellow at Ohio State University and received the M.S. degree.

He is the author of a number of technical articles and is a member of the American Institute of Electrical Engineers.

❖

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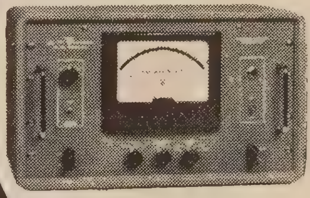

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PUBLISHED BY ROME CABLE DIV. OF ALCOA, ROME, N. Y.
PIONEERS IN INSTRUMENTATION CABLE ENGINEERING

SAGE MOVE? If possible, the Government will give serious attention to the prospect of converting the SAGE System to air traffic control. Motive for such a move is the statement by the USSR that it will build no more bombers. If this be the case, a new use for SAGE will have to be found, or our huge investment will have to be scrapped.

BIG BOUNCE. The Navy recently demonstrated a new communications system using the moon as a relay for radio signals. With the moon serving as a passive reflector, photographs have been transmitted from Pearl Harbor to Washington, D. C. Signals are received about 2½ seconds after transmission. This new system can only be used between points which have the moon above the horizon at the same time.

VOLT GETS A JOLT. Amplifiers using voltage may be in for competition from a non-electric device referred to as a fluid amplifier. Essentially such a device is a block of hard material with passages for the flow of a fluid. Elements include a power jet input which corresponds to a tube cathode, output jets which correspond to plates, and control jets which correspond to control grids. Amplification of 10 to 100 has been accomplished with pure fluid amplifiers. Priced lower than tubes or transistors, these amplifiers have no moving parts and are virtually invulnerable to the effects of extreme heat or cold, humidity, and shock.

BIG VOICE FROM LITTLE PACKAGE. It looks like the United States' Pioneer V will be sending signals from 50 million miles away come August. The 26-inch payload is outstanding from an electronic standpoint in that it includes an ultra-long-distance communications system built around two miniature transmitters—one 5-watt, the other 150-watt capacity. The power supply consists of 4,400 solar cells and rechargeable nickel cadmium batteries. Parametric amplifiers are being used for the first time in the front part of two of the ground receivers.

CABLEMAN'S CORNER. The subject of cable testing is an important one. This is the phase of production that determines whether or not the cable you are purchasing is in accordance with your standards and requirements. In the field of electronics and automation, cables are required to suit various stringent electrical, mechanical, and/or chemical environments. Many years of study and testing have gone into the design of test equipment to be used for these critical tests. It is not enough to know that a cable has been tested in a manner that is "essentially" the same as the required standard. Slight variations in equipment design or methods of tests can mean the difference between conformance and non-conformance. Make sure the test data you receive gives a true picture of the performance of your cable. When you need cable, call on a cable specialist. Phone Rome 3000, or write: Rome Cable Division of Alcoa, Dept. 12-50, Rome, New York.

These news items represent a digest of information found in many of the publications and periodicals of the electronics industry or related industries. They appear in brief here for easy and concentrated reading. Further information on each can be found in the original source material. Sources will be forwarded on request. ⑱

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Provides RANDOM ACCESS to all functions and ranges through the use of push-button switches.

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- Excellent stability.
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Laboratory Standards

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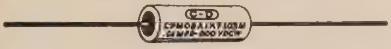

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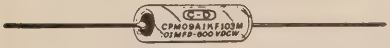

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TEMPERATURE RANGE: −55°C to +125°C without derating

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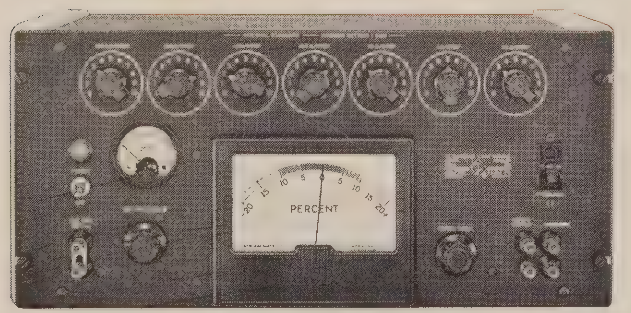

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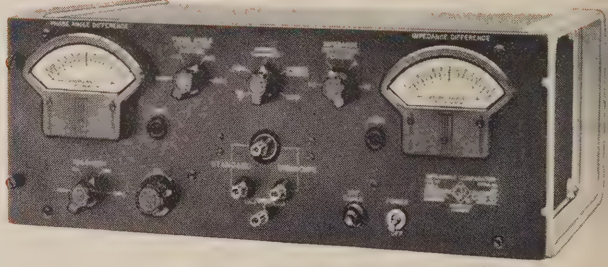

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Proceedings of the IRE

report of the Television Allocations Study Organization

NEW* Revolutionary† DO-T and DI-T TRANSISTOR TRANSFORMERS

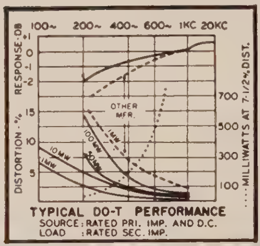
FROM STOCK—Hermetically Sealed to MIL-T-27A Specs.

UTC DO
UTC DI

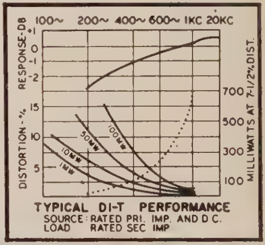
There is no transformer even twice the size of the DO-T and DI-T series which has as much as 1/10th the power handling ability . . . which can equal the efficiency . . . or equal the response range. And none to approach the reliability of the DO-T and DI-T units (proved to, but exceeding MIL-T-27A grade 4).

High Power Rating	up to 10 times greater.
Excellent Response	twice as good at low end.
Low Distortion	reduced 80%.
High Efficiency	up to 30% better . . . compare DCR.
Moisture Proof	hermetically sealed to MIL-T-27A.
Rugged	completely metal cased.
Anchored Leads	will withstand 10 pound pull test.
Printed Circuit Use	(solder melting) plastic insulated leads.
Suited to Clip Mounting	use Augat #6009-8A clip.

TRANSFORMERS PICTURED ACTUAL SIZE
DO-T: 5/16 Dia. x 13/32", 1/10 Oz.; DI-T: 5/16 Dia. x 1/4", 1/20 Oz.



TYPICAL DO-T PERFORMANCE
SOURCE: RATED PRI. IMP. AND D.C.
LOAD : RATED SEC. IMP.



TYPICAL DI-T PERFORMANCE
SOURCE: RATED PRI. IMP. AND D.C.
LOAD RATED SEC IMP

DO-T No.	Pri. Imp.	D.C. Ma.‡ in Pri.	Sec. Imp.	Pri. Res. DO-T	Pri. Res. DI-T	Mw. Level	DI-T No.
DO-T1	20,000 30,000	.5 .5	800 1200	850	815	50	DI-T1
DO-T2	500 600	3 3	50 60	60	65	100	DI-T2
DO-T3	1000 1200	3 3	50. 60	115	110	100	DI-T3
DO-T4	600	3	3.2	60		100	
DO-T5	1200	2	3.2	115	110	100	DI-T5
DO-T6	10,000	1	3.2	790		100	
DO-T7	200,000 500	0 0	1000 100,000	8500 —		25	
	Reactor 2.5 Hys./2 Ma., .9 Hy./4 Ma				630		DI-T8
DO-T8	" 3.5 Hys./2 Ma., 1 Hy./5 Ma.			630			
DO-T9	10,000 12,000	1 1	500 CT 600 CT	800	870	100	DI-T9
DO-T10	10,000 12,500	1 1	1200 CT 1500 CT	800	870	100	DI-T10
DO-T11	10,000 12,500	1 1	2000 CT 2500 CT	800	870	100	DI-T11
DO-T12	150 CT 200 CT	10 10	12 16	11		500	
DO-T13	300 CT 400 CT	7 7	12 16	20		500	
DO-T14	600 CT 800 CT	5 5	12 16	43		500	
DO-T15	800 CT 1070 CT	4 4	12 16	51		500	
DO-T16	1000 CT 1330 CT	3.5 3.5	12 16	71		500	
DO-T17	1500 CT 2000 CT	3 3	12 16	108		500	
DO-T18	7500 CT 10,000 CT	1 1	12 16	505		500	
DO-T19	300 CT	7	600	19	20	500	DI-T19
DO-T20	500 CT	5.5	600	31	32	500	DI-T20
DO-T21	900 CT	4	600	53	53	500	DI-T21
DO-T22	1500 CT 600	3 5	600 1500 CT	86 —	87	500	DI-T22
DO-T23	20,000 CT 30,000 CT	.5 .5	800 CT 1200 CT	850	815	100	DI-T23
DO-T24	200,000 CT 500 CT	0 0	1000 CT 100,000 CT	8500 —		25	
DO-T25	10,000 CT 12,000 CT	1 1	1500 CT 1800 CT	800	870	100	DI-T25
	Reactor 4.5 Hys./2 Ma., 1.2 Hys./4 Ma.				2300		DI-T26
DO-T26	" 6 Hys./2 Ma., 1.5 Hys./5 Ma.			2100			
	Reactor .9 Hy./2 Ma., .5 Hy./6 Ma.				105		DI-T27
DO-T27	" 1.25 Hys./2 Ma., .5 Hy./11 Ma.			100			
	Reactor .1 Hy./4 Ma., .08 Hy./10 Ma.				25		DI-T28
DO-T28	" .3 Hy./4 Ma., .15 Hys./20 Ma.			25			
DO-T29	120 CT 150 CT	10 10	3.2 4	10		500	
DO-T30	320 CT 400 CT	7 7	3.2 4	20		500	
DO-T31	640 CT 800 CT	5 5	3.2 4	43		500	
DO-T32	800 CT 1000 CT	4 4	3.2 4	51		500	
DO-T33	1060 CT 1330 CT	3.5 3.5	3.2 4	71		500	
DO-T34	1600 CT 2000 CT	3 3	3.2 4	109		500	
DO-T35	8000 CT 10,000 CT	1 1	3.2 4	505		100	
DO-T36	10,000 CT 12,000 CT	1 1.	10,000 CT 12,000 CT	950	970	100	DI-T36
*DO-T37	2000 CT 2500 CT	3 3	8000 Split 10,000 Split	195		100	
*DO-T38	10,000 CT 12,000 CT	1 1	2000 Split 2400 Split	560		100	
*DO-T39	20,000 CT 30,000 CT	.5 .5	1000 Split 1500 Split	800		100	
*DO-T40	40,000 CT 50,000 CT	.25 .25	400 Split 500 Split	1700		50	
*DO-T41	400 CT 500 CT	8 6	400 Split 500 Split	46		500	
*DO-T42	400 CT 500 CT	8 6	120 Split 150 Split	46		500	
*DOT-43	400 CT 500 CT	8 6	40 Split 50 Split	46		500	
*DO-T44	80 CT 100 CT	12 10	32 Split 40 Split	9.8		500	
DO-TSH	Drawn Hipermalloy shield and cover 20/30 db						DI-TSH

‡ DCMA shown is for single ended useage (under 5% distortion—100MW—1KC) . . . for push pull, DCMA can be any balanced value taken by .5W transistors (under 5% distortion—500MW—1KC)

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VOLUME 48, NUMBER 6, PART I

June, 1960

published monthly by The Institute of Radio Engineers, Inc.

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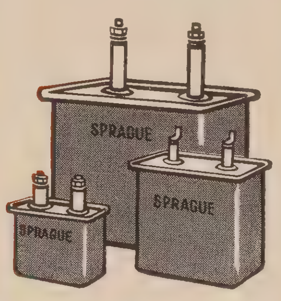
requirements
by a wide margin—



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The subject of power transmission by radio has been receiving increased attention with the advent of space vehicles. Jack Ramsay of our Department of Radar Systems discusses some of the factors involved in this problem.

The Philosophy and Ethics of Radio Power Transmission

There is considerable interest today in the feasibility of transmitting electrical power by radio instead of by transmission lines. Such a development presents a revolutionary situation in human society, for its repercussions can go far beyond the limits of radio and electrical engineering. Disregarding for the moment the possibilities inherent in the "wireless" transmission and control of power, let us review the fragmentary history of the subject.

The point-to-point transmission of electromagnetic power was first established by Hertz[1] in 1888. By proving experimentally that the "action at a distance" was produced by electric waves, Hertz established Maxwell's theory that light was an electromagnetic wave phenomenon. Thus the Hertzian waves were "dark" light, but could exert visible, audible, tangible and motional effects at a distance. Power, in fact, had been transmitted to a distance.

The first engineer to appreciate that power might be transmitted for useful purposes by electrical means through space appears to have been Tesla,[2] as he suggested the possibility in 1893.

In 1896, however, the power transmission aspect of electromagnetic waves was completely upset by Marconi's use of the waves for the transmission of intelligence. Wonderful results captured the imagination of the world, and for forty years had spectacular developments. Even today radio in most people's minds means radio communication—not Hertzian wave technology. Marconi himself, however, at a lecture[3] he delivered on "Radio Communication" in New York in 1927, very clearly prognosticated the power transmission as we now find it in the following succinct words:

"I hope I shall not be thought too visionary if I say that it may perhaps be possible that some day electromagnetic waves may also be used for the transmission of power, should we succeed in perfecting devices for projecting the radiation in parallel beams in such a manner as to minimize their dispersion and diffusion into space."

The solution was clearly in parallel beam transmission. Now Rayleigh[4, 5] in 1881 and 1891 had laid down the optical theory of parallel beam transmission in papers on the "Pinhole Camera." Parallel beam transmission to a range R_r (the "Rayleigh Range") would be possible if the relation $R_r = \frac{1}{2} D^2/\lambda$ were suitably satisfied, where D is the antenna dimension and λ the wavelength. In 1927 the antennas were too small and the metric wavelengths too large for R_r to have significant length; the time was not ripe.

In 1936 decimetre waves were generated by vacuum tubes. The interest, however, shifted from transmission through space to transmission through pipes, a facility theoretically established, again by Rayleigh, in 1898. The main objective of the technique was communication by Hertzian waves, this time in pipes.

About this time electro-optics found its major quasi-optical application in the development of radar, "seeing" by black light electrically generated, detected, amplified and displayed. By the mid 1940s generators of a few average kilowatts were available at 10 cm wavelength. Antennas which would have had Rayleigh ranges of hundreds of yards were built for the radars. The interest, however, was in information, as in radio, and not in power techniques.

Table
POWER TRANSMISSION WITH ELECTROMAGNETIC WAVES

FREQUENCY RANGE	REFERENCE WAVELENGTH	PROJECTOR SIZE	RAYLEIGH RANGE
Microwave	1 cm	100 ft.	29 miles
Infra-red	1 micron	1 inch	1060 ft.
Optical	5000 A	1 mm	1 meter

The range is directly proportional to the square of the antenna dimension, and inversely proportional to the wavelength, since $R_r = \frac{1}{2} D^2/\lambda$.

Development of power tubes continued but two outstanding antenna applications came to improve the picture. Antennas for radio astronomy and for tropospheric scatter communications had to be very large to be effective. Quasi-optical mirror antennas, designed largely on the principles used by Hertz, reached a size of 250 feet in the 1950s. With the generators available, it became evident that in Rayleigh's formula D was now large enough and λ small enough to make $\frac{1}{2} D^2/\lambda$ a matter of miles. Hundreds of average kilowatts could be transmitted using the newer tube generators assembled in aggregates.

In 1952 a demonstration[6] at the London Physical Society showed power transmission with small "dispersion and diffusion into space" on a model millimeter-wave exhibit. In 1959 publicity[7, 8] in this country (the U.S.A.) was given to a project for transmitting enough power vertically by microwaves to support a helicopter and radar equipment. Here in fact was to be Hertz's action at a distance fully realized. Not only would the beam be sharp but also it would be focused. Microwave optical engineering was born, a power engineering derived from Faraday's experiments and Maxwell's equations, and the long history via Rayleigh of classical optics.

Microwave optical power transmission technique requires efficient antenna systems of large size, and efficient generators and converters of high power. Present antenna efficiencies are around 60 percent and generator efficiencies (primary power to microwave power) are 50 percent. The conversion efficiency depends on the type of converter used. Assume the microwave power received simply heats water with 100-percent efficiency. Then the efficiencies are:

Generator	0.50
Transmitting Antenna	0.60
Propagation	0.60
Receiving Antenna	0.60
Over-all Efficiency	0.108

Since no one has as yet constructed a high power long range system, these figures are quite conjectural. For an experiment, two 60-foot antennas spaced a mile apart would, at 10 cm wavelength, provide an interesting check of the above 11-percent figure.

To emphasize the role the antenna size plays in this technique, assume we might use 600-foot antennas. (A 600-foot radio telescope is presently under construction.) Then the range would be 100 miles!

There are many situations where beam transmission is attractive, e.g. to islands, up mountains, across valleys, over deserts, and in the Arctic or Antarctic. Also, isolated atomic power stations may beam the power to inhabited areas.

It is, however, in outer space where beam transmission may find its most extensive application. There being no significant atmosphere, millimeter, sub-millimeter, infrared and optical wavelengths can be used, and the antenna sizes reduce to inches (see Table). Rayleigh calculated that a four-inch aperture antenna would have a "Rayleigh Range" of 5 miles. Current interest in optical and infra-red generators and in the ASER (Amplification by Stimulated Emission of Radiation) technique, may lead, in lasers and irasers, to compact, lightweight sources for outer space use.

The subject of power transmission by diffracted beams cannot be left without a warning of the inherent danger in the use of this disembodied high power; this matter is as serious as that of atomic radiation. The danger to man, to animals and birds, to crops and vegetation, to aircraft, to buildings and equipment make this development, as in the case of atomic energy, a double-edged endeavor. Careless exploitation of this hazardous form of energy must be prevented by government legislation and international agreements.

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6. "Rayleigh Range Transmission," Demonstration at the Physical Society Exhibition, London, 1952.
7. "Powering Recon. Platforms," B. Kovit, Space/Aeronautics, Vol. 33, pp. 145-147, February 1960.
8. "Applying Microwaves to Space Problems," H. M. Hart, Electronic Industries, Vol. 19, pp. 78-82, April 1960.

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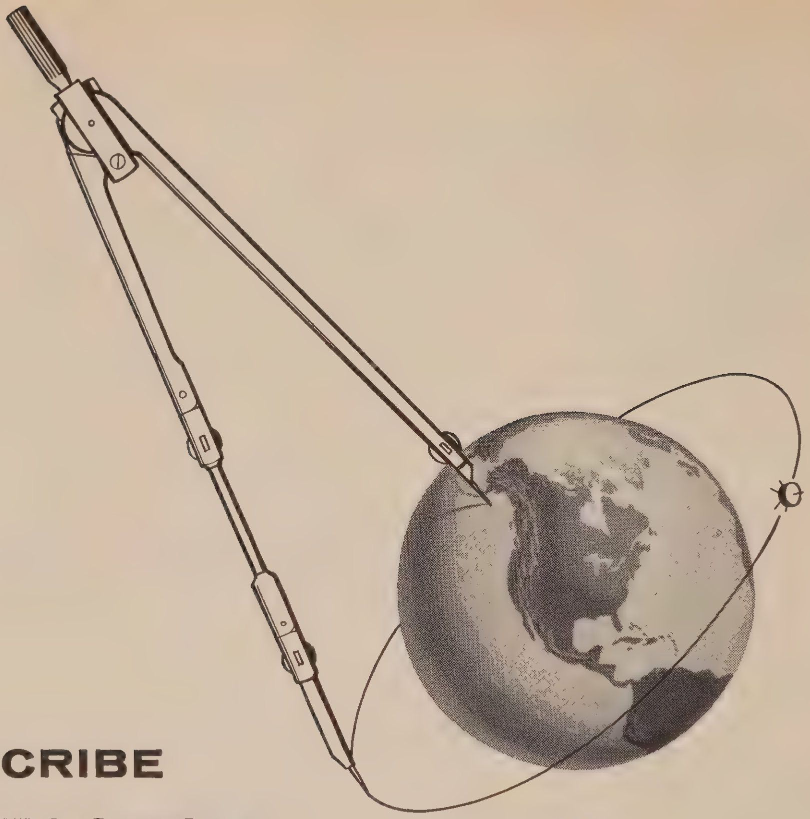

HOW TO SCRIBE A "PERFECT" CIRCLE IN OUTER SPACE

Bell Laboratories guidance system achieves unprecedented accuracy in steering Tiros weather satellite into orbit

Equipped with TV cameras, tape recorders, solar cells and antennas, the world's most advanced weather satellite, the NASA Tiros I, had to be placed in a precisely circular orbit at a specified altitude to do its job well.

The "shot" was a virtual bull's-eye. The mean altitude was within *one mile* of that planned. And the deviation from this mean was less than ½ per cent, making it the most-nearly-perfect circular orbit ever achieved with a space vehicle by either the United States or Russia.

Two Bell Laboratories engineers, T. J. Grieser and D. R. Hagner, look over the second-stage section of the Air Force Thor-Able missile used to launch the NASA Tiros weather satellite.

The dependability and accuracy of Bell Laboratories' ground-controlled Command Guidance System has been proven before—in the successful test flights of the Air Force Titan intercontinental ballistic missile, and in last year's Air Force Thor-Able re-entry test shots from which the first nose-cone recoveries were made at ICBM distance. Now, with Tiros, the system contributes to a dramatic *non*-military project. Other uses are in the offing.

This achievement in precise guidance again illustrates the versatility of Bell Laboratories' research and development capabilities—directed primarily toward improving your Bell Telephone service.

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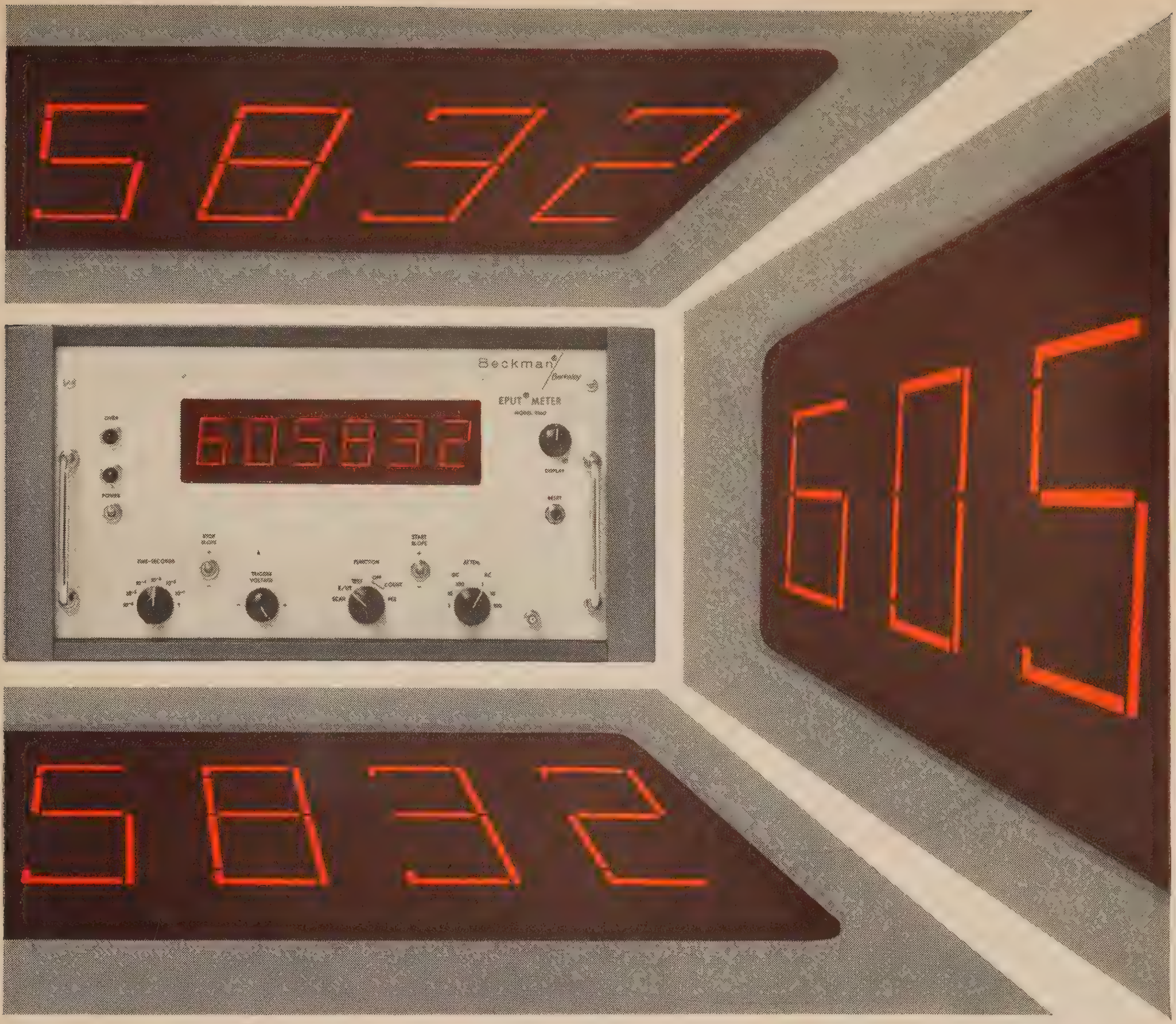

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New Beckman counter display is right out front, visible from any angle and ***unobscured by interposed elements.*** *Most EPUT® meters, timers and other Beckman counters are now available with this bright red in-line display 1-1/2" high. The display is carefully designed to minimize reader fatigue and prevent reading errors. Because the digits are formed by illuminated segments on the face of the panel, the indication can be read from almost any position in front of the instrument—from above or from either side at angles as close as 30° to the panel. Deep red color makes the display stand out boldly in brightly lit rooms—even in sunlight. The price per digit is only $30 to $45 more than the price of counters with the standard vertical column display.*

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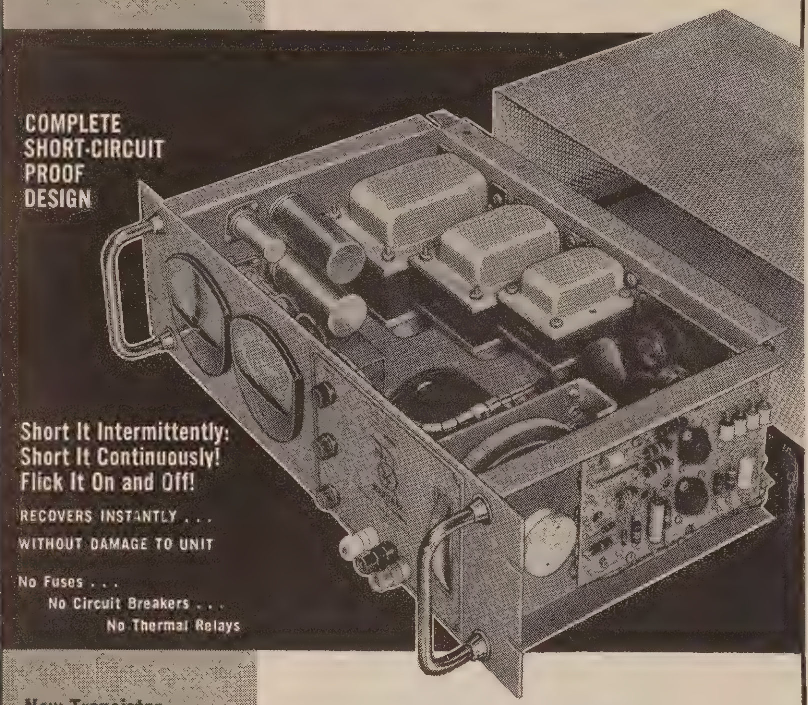
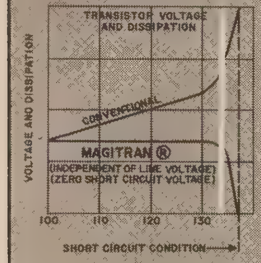


New Transistor-Magnetic Designs Obsoletes Conventional Transistor, Vacuum Tube and Related Types



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Combines The Advantages Of
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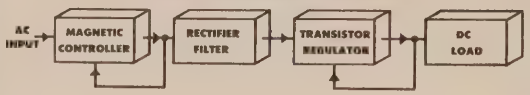

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Model No.	Voltage VDC	Current Amps	Regulation Line	Regulation Load	Ripple V RMS	Price FOB Factory
TR36-4M	0-36	0-4	± 0.05%	0.1%	0.01%	$495
TR36-8M	0-36	0-8	± 0.05%	0.1%	0.01%	545
TR36-12M	0-36	0-12	± 0.05%	0.1%	0.01%	655
TR36-20M	0-36	0-20	± 0.05%	0.1%	0.02%	895
TR160-1M	10-160	0-1	± 0.05%	0.05%	0.01%	495
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Models listed are stock units normally available for quick delivery. 400 cycle models also available. Also special designs made to customers specifications. Write for quotations.

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Meetings with Exhibits

● As a service both to Members and the industry, we will endeavor to record in this column each month those meetings of IRE, its sections and professional groups which include exhibits.

Δ

June 20-21, 1960

Chicago Spring Conference on Broadcast and Television Receivers, Graemere Hotel, Chicago, Ill.

Exhibits: Mr. Stanley Hopper, Zenith Radio Corp., 6001 W. Dickens Ave., Chicago 39, Ill.

June 27-29, 1960

National Convention on Military Electronics, Sheraton-Park Hotel, Washington, D.C.

Exhibits: Mr. L. David Whitelock, BuShips, Electronics Div., Dept. of Navy, Washington, D.C.

August 1-3, 1960

Fourth Global Communications Symposium, Hotel Statler, Washington, D.C.

Exhibits: Mr. Robert F. Brady, Office of the Chief Signal Officer, U. S. Army Signal Corps, Pentagon, Washington, D.C.

August 23-26, 1960

WESCON, Western Electronic Show and Convention, Memorial Sports Arena, Los Angeles, Calif.

Exhibits: Mr. Don Larson, WESCON, 1435 LaCienega Blvd., Los Angeles, Calif.

September 9-10, 1960

Conference on Communications, Tomorrow's Techniques—A Survey. Roosevelt Hotel, Cedar Rapids, Iowa.

Exhibits: Mr. D. O. McCoy, 2315 Blake Blvd., Cedar Rapids, Iowa.

September 19-22, 1960

National Symposium on Space Electronics & Telemetry, Shoreham Hotel, Washington, D.C.

Exhibits: Mr. Leon King, Jansky and Bailey, Inc., 1339 Wisconsin Ave., N.W., Washington, D.C.

October 3-5, 1960

Sixth National Communications Symposium, Hotel Utica & Utica Municipal Auditorium, Utica, N.Y.

Exhibits: Mr. R. E. Bischoff, 19 Westminster Road, Utica, N.Y.

October 10-12, 1960

National Electronics Conference, Hotel Sherman, Chicago, Ill.

Exhibits: National Electronics Conference, Inc., 228 North La Salle St., Chicago 1, Ill.

October 19-21, 1960

Symposium on Space Navigation, Deshler-Hilton Hotel & Civic Center, Columbus, Ohio

Exhibits: Mr. William P. McNally, 35 Laurel St., Floral Park, L.I., N.Y.

(Continued on page 10A)

PRECISION ALIGNMENT FOR MISSILE SYSTEMS

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DIMENSIONS: 8¾" x 19" rack panel, 13" deep. Suitable for rack mount — supplied also with cabinet.

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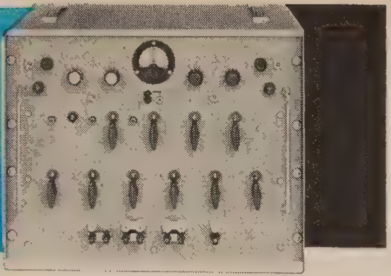

–measures both in-phase and quadrature voltage ratios – with high accuracy

This instrument cancels quadrature effects, giving a sharp, true null.

In eliminating quadrature voltage, this Gertsch bridge achieves an in-phase ratio accuracy as good as 0.001%. Quadrature voltage ratios are read as rectangular coordinates, tangent of phase-shift angle, or magnitude of phase-shift angle in degrees directly.

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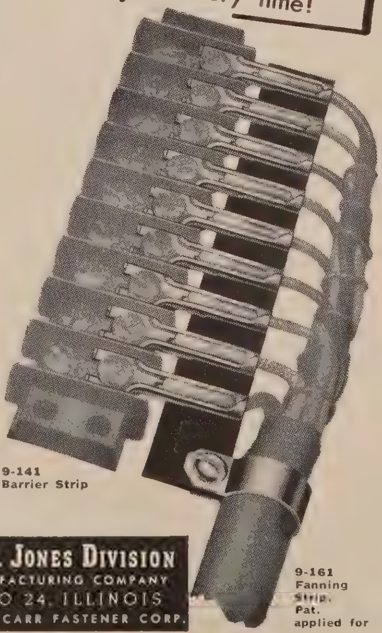

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Meetings with Exhibits

(Continued from page 8A)

October 24-26, 1960

East Coast Aeronautical & Navigational Electronics Conference, Lord Baltimore Hotel, Baltimore, Md.

Exhibits: Dr. Harold Schutz, Westinghouse Electric Corp., Air Arm Div., P.O. Box 746, Baltimore, Md.

October 26-28, 1960

Fifth Annual Conference on Non-Linear Magnetics and Magnetic Amplifiers, Bellevue-Stratford Hotel, Philadelphia, Pa.

Exhibits: J. L. Whitlock Associates, 6044 Ninth St., North, Arlington 5, Va.

Oct. 31-Nov. 2, 1960

13th Annual Conference on Electrical Techniques in Medicine & Biology, Sheraton-Park Hotel, Washington, D.C.

Exhibits: Mr. Lewis Winner, 152 West 42nd St., New York 36, N.Y.

November 14-16, 1960

Mid-American Electronics Convention (MAECON), Hotel Muehlebach, Kansas City, Mo.

Exhibits: Dr. L. R. Crissman, Trans World Airlines, Kansas City, Mo.

November 15-17, 1960

Northeast Electronics Research & Engineering Meeting (NEREM), Boston Commonwealth Armory, Boston, Mass.

Exhibits: Miss Shirley Whitcher, IRE Boston Office, 73 Tremont St., Boston, Mass.

December 1-2, 1960

PGVC Annual Meeting, Sheraton Hotel, Philadelphia, Pa.

Exhibits: Mr. E. B. Dunn, Atlantic, Refining Co., 260 S. Broad St., Philadelphia 1, Pa.

December 11-14, 1960

Eastern Joint Computer Conference, Hotel New Yorker, New York, N.Y.

Exhibits: Mr. Alan D. Meacham, 120 E. 41st St., New York 17, N.Y.

January 9-11, 1961

Seventh National Symposium on Reliability and Quality Control in Electronics, Bellevue-Stratford Hotel, Philadelphia, Pa.

Exhibits: Mr. James H. Goodman, Burroughs Research Center, Building #3, Room 3307, Paoli, Pa.

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Note on Professional Group Meetings: Some of the Professional Groups conduct meetings at which there are exhibits. Working committeemen on these groups are asked to send advance data to this column for publicity information. You may address these notices to the Advertising Department and of course listings are free to IRE Professional Groups.

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SAME-DAY SHIPMENT OF STANDARD DELTAMAX CORE SIZES

Arnold 6T tape cores (aluminum-cased and hermetically-sealed) offer you three very important design advantages. *One:* Maximum compactness, comparable to or exceeding that previously offered only by plastic-cased cores. *Two:* Maximum built-in protection against environmental hazards. *Three:* Require no supplementary insulation prior to winding and can be vacuum impregnated after winding.

Now we've added a fourth vital advantage: Maximum availability. An initial stock of approximately 20,000 Deltamax 1, 2 and 4-mil tape cores in the proposed EIA standard sizes (See AIEE Publication No. 430) is ready on warehouse shelves for your convenience. From this revolving stock, you can get immediate shipment (*the same day order is received*) on cores in quantities from prototype lots to regular production requirements.

Use Arnold 6T cores in your designs for improved performance and reduced cost. They're guaranteed against 1000-volt breakdown . . . guaranteed to meet military test specifications for resistance to vibration and shock . . . guaranteed also to meet military specifications for operating temperatures. The 6T hermetic casing method is extra rigid to protect against strains.

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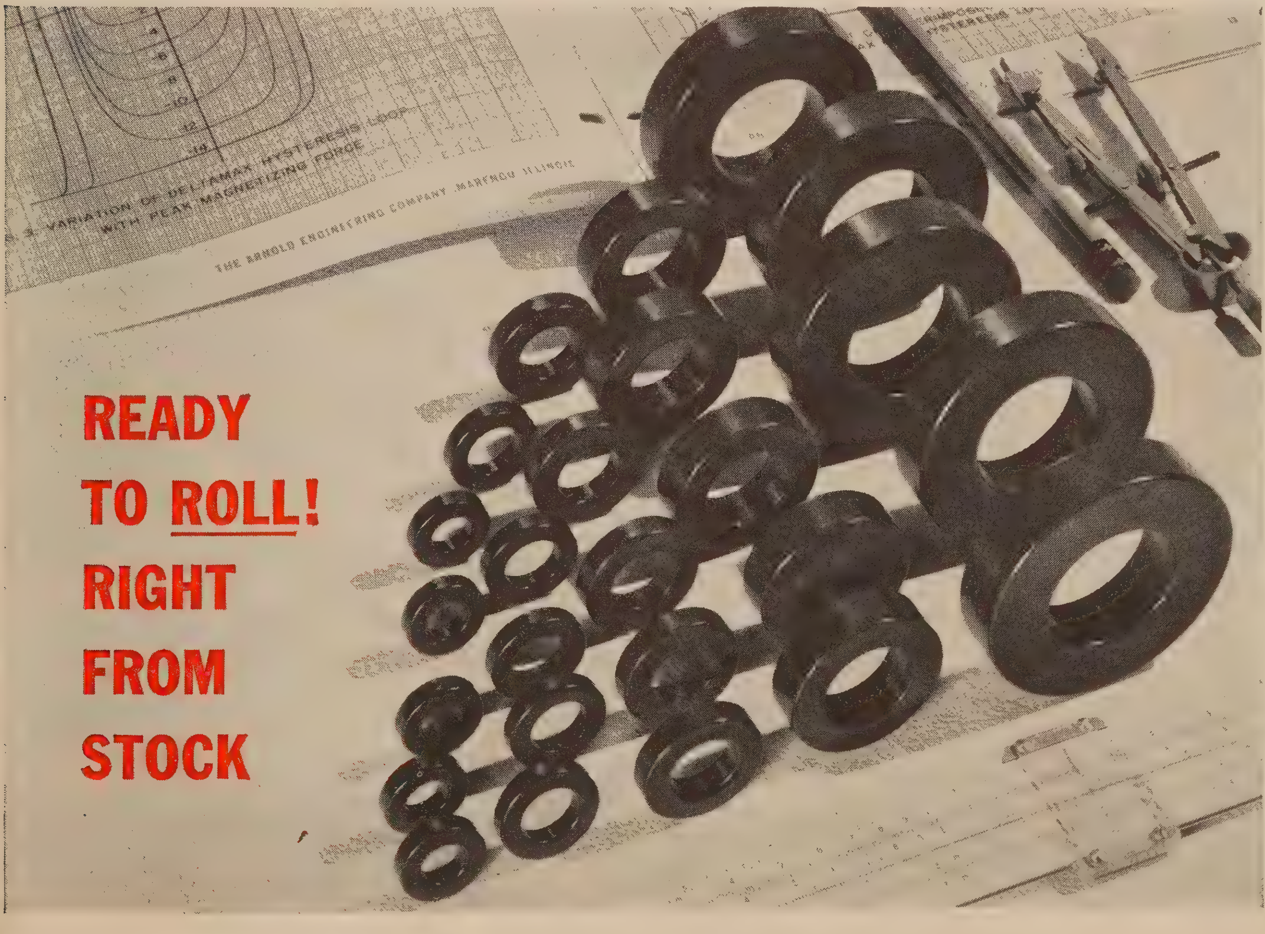
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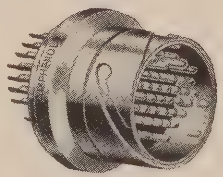

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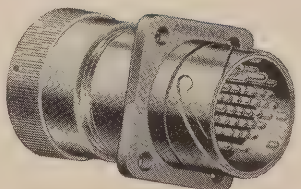

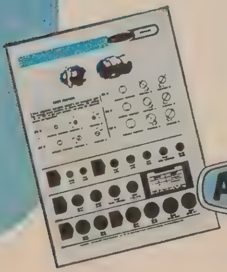

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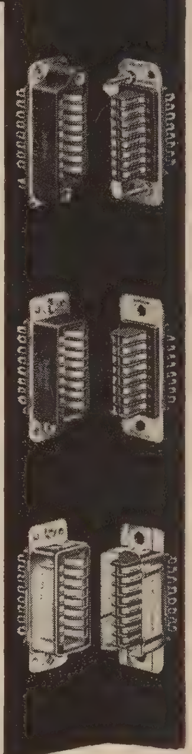

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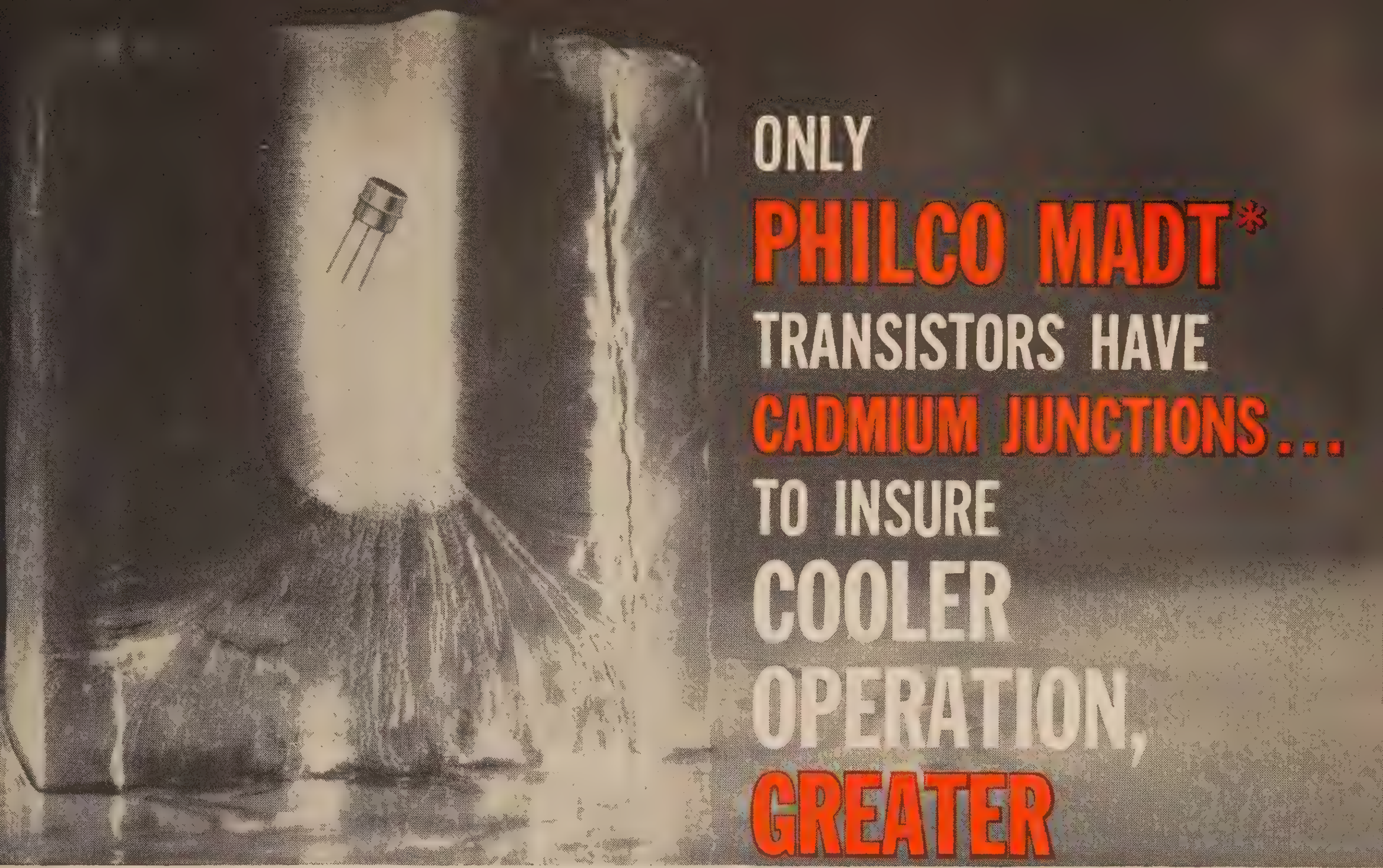

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Philco Micro Alloy Diffused-base Transistors (MADT) are now manufactured with cadmium junctions. This is another major advancement in transistor engineering . . . developed and offered exclusively by Philco! The higher thermal conductivity of cadmium insures cooler-running junctions for any given power dissipation . . . providing far greater transistor reliability and an extra margin of safety. It permits rating high-frequency germanium transistors for 100°C maximum junction temperature. Cadmium permits higher power dissipation, higher storage temperature, and improved capacity to withstand temporary overload. In addition to these advantages of cadmium, Philco MADT transistors have retained all the proven superb characteristics of the famous MADT line:

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- low saturation voltage
- high beta and excellent beta linearity with temperature and current
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- low noise figure

The Philco MADT line, now with cadmium junctions, include:

AMPLIFIERS	SWITCHES
2N502 2N502A 2N503 2N588 2N1158 2N1158A	2N501 2N501A 2N1204 2N1494 2N1495 2N1496 2N1500

For complete specifications and applications data, write Dept. IR-660.

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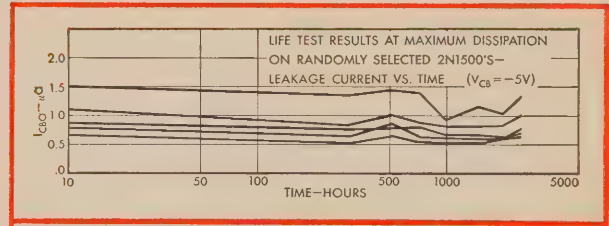

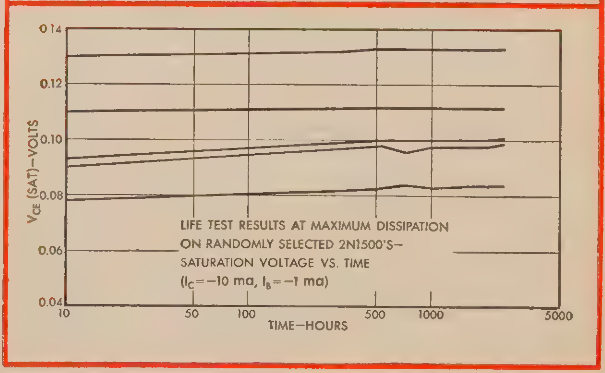

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IRE News and Radio Notes

CURRENT IRE STATISTICS

(As of April, 30, 1960)

Membership—80,869
Sections*—106
Subsections*—27
Professional Groups*—28
Professional Group Chapters—265
Student Branches†—191

* See May, 1960, issue for a list.
† See this issue for a list.

Calendar of Coming Events and Authors' Deadlines*

1960

- **Radio Frequency Interference Symp., Shoreham Hotel, Washington, D.C., June 13–14.**
- **Chicago Spring Conf. on Broadcast and Television Receivers, Graemere Hotel, Chicago, Ill., June 20–21.**
- **Conf. on Standards and Electronic Measurements, NBS Boulder Labs., Boulder, Colo., June 22–24.**
- **Workshop on Solid State Electronics, Purdue Univ., Lafayette, Ind., June 23–24.**
- **Natl. Conv. on Mil. Elec., Sheraton Park Hotel, Washington, D. C., June 27–29.**
- **Cong. Intl. Federation of Automatic Control, Moscow, USSR, June 25–July 9.**
- 7th Ann. Symp. on Computers and Data Processing, Stanley Hotel, Estes Park, Colo., July 28–29.
- 4th Global Communications Symp., Hotel Statler, Washington, D. C., Aug. 1–3.
- AIEE Pacific Gen. Mtg., El Cortez Hotel, San Diego, Calif., Aug. 9–12.
- **WESCON, Los Angeles Mem. Sports Arena, Los Angeles, Calif., Aug. 23–26.**
- **Int'l. Information Theory Mtg., London, Eng., Aug. 29-Sept. 3.**
- **Int'l Conf. on Electrical Engrg. Education, Sagamore Conf. Center, Syracuse Univ., Syracuse, N.Y., Sept.**
- EIA Conf. on Value Engrg., Disneyland Hotel, Anaheim, Calif., Sept. 7–8.
- URSI 13th Gen. Assembly, Univ. of London, London, Eng., Sept. 5–15.
- **Joint Automatic Control Conf., M.I.T., Cambridge, Mass., Sept. 7–9.**
- **Conf. on Communications, Roosevelt Hotel, Cedar Rapids, Iowa, Sept. 9–10.**
- 4th Ann. Joint Mil. Ind. Electronic Test Equip. Symp., Chicago, Ill., Sept. 14–15.
- **8th Ann. Engrg. Management Conf., Morrison Hotel, Chicago, Ill., Sept. 15–16.**
- **Int'l Symp. on Data Transmission, Delft, Netherlands, Sept. 19–21.**
- **Space Electronics and Telemetry Conv. and Symp., Shoreham Hotel, Washington, D.C., Sept. 19–22.**

* DL = Deadline for submitting abstracts.

(*Continued on page 18A*)

MAECON PRESENTS "THE SEMICONDUCTOR 60's"

The 12th annual MAECON will be held November 15 and 16, 1960, at the Hotel Muehlebach in Kansas City, Mo. As its theme suggests, this year's Mid-America Electronics Conference will feature sessions on semiconductors; a full program both days will be devoted to this subject. Concurrent sessions one day will be devoted to microwaves; concurrent sessions the other day will be on engineering education and management.

MAECON is sponsored by the Kansas City Section of the IRE, this year with the assistance of the Lincoln-Omaha Section and the Wichita Section. In addition to the technical paper sessions, there will be exhibits, a ladies program, and a banquet on Tuesday evening, November 15.

For additional information, contact MAECON Chairman, L. R. Crissman, Trans World Airlines, 10 Richards Road, Kansas City, Mo.

DR. ERNST WEBER HONORED BY IRE STANDARDS COMMITTEE

Dr. Ernst Weber, President of the Polytechnic Institute of Brooklyn, was guest of honor of the IRE Standards Committee at its Annual Luncheon on March 22, 1960 at the Harvard Club in New York.

Dr. Weber, 1959 President of the IRE, has long been active in the IRE's standardization activities. He started as a member of a Subcommittee of the Circuits Committee and progressed through the Technical Committees to serve finally as Chairman of the IRE Standards Committee.

President Ronald McFarlan read and presented the following letter of Commendation to Dr. Weber at the luncheon:

"Dear Ernst:

"On the occasion of the Annual Luncheon Meeting of the Standards Committee, it has become conventional to recognize by public acknowledgement a person who has made a major contribution to the advance of the Standards work of the IRE. This year you have been chosen for this honor.

"It hardly seems necessary to review the long list of IRE committee activities you have engaged in, and the other positions you have held on behalf of the IRE. In some respects your standards work was a stepping stone to providing the IRE with an outstanding President. In other respects it may be considered a contribution to our industrial society through the widespread educational and standardization work of the IRE.

"It is a happy occasion for me to be able to read this letter to you at this Annual Luncheon Meeting. It adds one more to the list of honors you have achieved as a result of your devotion to IRE and our profession. It represents in this case the particular acknowledgement of your colleagues for your work in the field of standards.

"I congratulate you and at the same time express the hope that the heavy duties which you have assumed at your institution will not diminish your interest and participation in the standards work of the IRE."

M.I.T. WILL CONDUCT SUMMER COURSE ON RADAR ASTRONOMY

A one-week course on Radar Astronomy will be given in the M.I.T. Summer Session from Monday, August 22 through Friday, August 26. The course will include discussions of the physics of the upper atmosphere and extended solar atmosphere, recent advances in the high-powered radar art and recent results in the exploration by radar of the upper atmosphere, the moon and the nearest planets. The lectures will be given by staff members of the Massachusetts Institute of Technology Lincoln Laboratory and the Electrical Engineering Department, assisted by guest lecturers from other universities. The program will be under the general direction of Dr. John V. Harrington, Head of the Radio Physics Division of the M.I.T. Lincoln Laboratory.

A recent meeting of the PGME administrative committee in the Sheraton Hotel, Philadelphia, Pa. where plans for the 1960 program were reviewed, *left to right:* E. F. MacNichol, Jr., Johns Hopkins University; John W. Moore, National Institutes of Health; R. L. Bowman, National Institutes of Health; Lee B. Lusted, University of Rochester School of Medicine, editor PGME TRANSACTIONS; Lester E. Flory, RCA Laboratories, vice-chairman PGME; G. N. Webb, Johns Hopkins Hospital, secretary-treasurer PGME; Walter E. Tolles, Airborne Instruments Laboratory, PGBME chairman; Vladimir K. Zworykin, Rockefeller Institute; Carl Berkley, Rockefeller Institute; Otto H. Schmitt, University of Minnesota; Urner Liddel, National Institutes of Health; and J. M. Reid, Moore School of Electrical Engineering, University of Pennsylvania, editor of PGME *Newsletter*.

PROCEEDINGS COMPUTER ISSUE SUBMITS CALL FOR PAPERS

The Institute of Radio Engineers will publish a special Computer Issue of the PROCEEDINGS in January, 1961. Papers on *new developments* in digital and analog computers are desired for publication in this issue, especially in the following areas: Components; Storage Devices and Systems; Arithmetic, Logic, and Control Elements, including Self-organizing Machines; Input and Output Elements, including Voice and Pattern Recognition, and Displays; Logical Design, including Use of Computers in Logical Design; Circuit Design, including Use of Computers in Circuit Design; General Purpose Computers and Data Processors; Computers Optimized for Special Roles; Large Systems in which Computers Play a Role; Digital Communication; and Microminiaturization.

The deadline for papers is July 29, 1960. Papers must include a 100-word abstract. Three copies of the paper and illustrations are required. Also include one set of illustrations that are reproducible, and photographs and biographies of the authors. Manuscripts should be sent to E. K. Gannett, Managing Editor, IRE, 1 East 79th Street, New York 21, N. Y. Indicate clearly that the paper is intended for the Computer Issue.

MAGNETICS CONFERENCE TO BE HELD IN OCTOBER

The fifth annual Conference on Non-Linear Magnetics and Magnetic Amplifiers will be held on October 26–28, 1960. The conference is sponsored by the AIEE Committee on Magnetic Amplifiers and the IRE Professional Group on Industrial Electronics with cooperation from the Professional Group on Electronic Computers.

The technical program will consist of sessions devoted to:

I. Computer Magnetics.
   a) Magnetic memory components, devices and systems.
   b) Magnetic logic elements and circuits.

II. Combined Semiconductor and Non-Linear Magnetic Devices.

III. Theory Design and Application of Magnetic Amplifiers.

This would include such topics as low level amplifiers, high frequency operation of magnetic amplifiers, ferroresonant circuitry and magnetic devices for extreme environments.

ELECTROTECHNICAL COMMISSION TO MEET IN NEW DELHI, INDIA

A tentative program for the 25th General Meeting of the International Electrotechnical Commission in New Delhi, India, October 31 through November 12, has been announced by the U. S. Technical Committee of the IEC, an arm of the American Standards Association.

Twenty-three technical committees, with delegates from the 35 member nations of the IEC, will be in attendance.

Vice Admiral G. F. Hussey, Jr., Managing Director of the American Standards Association, has expressed the desire for strong American participation at the meeting.

During and after the General Meeting, visits of technical interest are being planned for the attending delegates. In addition, it has been proposed that a special exhibition be held in New Delhi of electrical undertakings and industries in India; this will enable delegates to obtain a clear understanding of the developments in the electrotechnical field now taking place in all parts of the country. During the course of the meeting there will be a one-day visit to the Bhakra Nangal Project, one of India's largest multipurpose ventures, covering both irrigation and power generation. Among the other sites scheduled to be seen by the delegates is the National Physical Laboratory, which is the national center for maintaining the ultimate standards for all physical measurements. The All India Radio, the central organization responsible for broadcasting in India, will also be seen by attending delegates.

Completing plans for the Broadcast Television Receivers Spring Conference are (*back row, left to right*): Neil Friehart, Motorola, Inc.; W. G. Henke, Admiral Corp.; Jack Bridges, Warwick Mfg. Co.; S. Hopper, Zenith; and D. Smithana, J. G. Twist Co. Seated, *left to right*, are Lin Kao, Admiral Corp.; Pieter Fockens (Chairman), Zenith; D. Eckhardt, Sylvania; and Max Beier, Motorola, Inc.

Calendar of Coming Events and Authors' Deadlines*

(*Continued from page 16A*)

Industrial Elec. Symp., Manger Hotel, Cleveland, Ohio, Sept. 21–22,
10th Ann. Broadcast Symp., Willard Hotel, Washington, D.C., Sept. 23–24.
Sixth Natl. Communications Symp., Hotel Utica and Utica Municipal Aud., Utica, N. Y., Oct. 3–5. (DL*: June 1, B. H. Baldridge, 25 Bolton Rd., New Hartford, N. Y.)
PGNF 7th Ann. Mtg, Gatlinburg, Tenn., Oct. 3–5.
6th Conf. on Radio Interference Reduction, Chicago, Ill., Oct. 4–6.
Natl. Elec. Conf., Hotel Sherman, Chicago, Ill., Oct. 10–12. (DL*: May 1960 Prof. T. F. Jones, Jr., School of E.E., Purdue Univ., Lafayette, Ind.)
2nd Natl. Ultrasonics Symp., Boston, Mass., Oct.
Engrg. Writing and speech Symp., Bismark Hotel, Chicago, Ill., Oct. 13–14.
Symp. on Space Navigation, Deshler-Hilton Hotel, Columbus, Ohio, Oct. 19–21, (DL*: July 15, J. D. Kraus, Ohio State Univ. Radio Observatory, Columbus.)
East Coast Conf. on ANE, Lord Baltimore Hotel, Baltimore, Md., Oct. 24–26. (DL*: June 6, S. Hershfield, The Martin Co., Baltimore, Md.)
5th Ann. Conf. on Nonlinear Magnetics and Magnetic Amplifiers, Bellevue-Stratford Hotel, Philadelphia, Pa., Oct. 26–28.
Electron Devices Mtg., Hotel Shoreham, Washington, D. C., Oct. 27–29.
13th Ann. Conf. on Elec. Tech. in Med. and Bio., Sheraton Park Hotel, Washington, D. C., Oct. 31, Nov. 1–2.
Radio Fall Mtg., Hotel Syracuse, Syracuse, N. Y., Oct. 31, Nov. 1–2.
Symp. on Communications, Queen Elizabeth Hotel, Montreal, Quebec, Canada, Nov. 4–5.
Symp. on Space Instrumentation, Washington, D.C., Nov. 8–9.
6th Ann. Conf. on Magnetism and Magnetic Materials, New Yorker Hotel, N. Y., N. Y., Nov. 14–17. (DL*: Aug. 26, A. M. Clogston, R. C. Fletcher, Bell Tel. Labs., Murray Hill, N. J.)
Mid-Amer. Elec. Conv., Hotel Muehlebach, Kansas City. Mo., Nov. 15–16. (DL*: June 15, J. Austin, Bendix Aviation Corp., 95 and Troost, Kansas City, Mo.)
PGPT Ann. Conf., Boston, Mass., Nov. 15–16. (DL*: June 1, C. W. Watt, Raytheon Co., Waltham, Mass.)
1960 NEREM (Northeast Electronics Res. & Engrg. Mtg.), Boston, Mass., Nov. 15–17.
PGVC Ann. Mtg., Sheraton Hotel, Philadelphia, Pa., Dec. 1–2, (DL*: July 15, W. G. Chaney, American Telephone and Telegraph Co., 195 Broadway, N. Y. 7, N. Y.)
3rd EIA conf. on Maintainability of Electronic Equipment, Hilton Hotel, San Antonio, Tex., Dec. 5–7.
Eastern Joint Computer Conf., New Yorker Hotel, New York, N.Y., Dec. 13–15. (DL, papers: Aug. 13, E. Kubie, Computer Usage Co., 18 E. 41 St., N.Y. 17, N.Y.)

* DL = Deadline for submitting abstracts.

1960 WESCON to Be Held In August at Los Angeles

The nation's electronics engineering authors have been invited to help build a WESCON technical convention "that will aim at new standards for the exchange of technical information."

The Western Electronic Show and Convention will be staged August 23–26 in Los Angeles' new Memorial Sports Arena.

The call for papers was issued by Richard G. Leitner of System Development Corporation, chairman of WESCON's technical program committee, who outlined policies intended to bypass traditional technical meeting formats in favor of a more flexible convention in which the quality of technical contributions will actually shape the final program. Some of these policies, as released by Mr. Leitner on behalf of his committeemen, are:

1) The senior scientists on the committee are charged with compiling the most significant technical information available in each special field.

2) "Solicited" papers will play a major role in the program. They will differ from "invited" papers in that their eventual inclusion in the program is not guaranteed but will depend on their quality.

3) The technical program will operate on three "levels of interest," which are defined as a) purely theoretical; b) system engineering, or high-level applied engineering concepts; and c) "how to" subjects.

4) Since the quality and timeliness of the technical contributions will shape the program's format, there will be no standard requirement as to length or composition of papers. "Some technical papers have five significant minutes and 20 minutes of padding," Leitner said. "We're interested only in the important five minutes, and will accept discussions of varying lengths."

Applying these policies to the big job of producing a four-day technical program calls for new approaches. "We can't predict, for instance, how many actual sessions will be staged, since the quality and variety of papers themselves will determine that number," Mr. Leitner said. He also stated that sessions won't necessarily correspond to IRE professional groups.

"The professional groups which can produce really outstanding sessions on their subjects will be encouraged in every way," he said, "but we do not feel bound to include sessions in which the papers are relatively undistinguished."

He said his committee will require 1000-word abridgments of technical papers for consideration (where the full paper is not available) rather than the 150-word abstracts which have been acceptable for most technical conferences. May 1 is the final deadline for these abridgments.

The element of showmanship as a means of increasing the impact and interest in sessions is also being stressed by the WESCON technical program committee. Efforts will be made to set up "clinics"—through the engineering writing and speech groups in IRE sections—to help authors prepare their material for WESCON.

The reading of papers will be "definitely discouraged," and the clinics will provide editing services and advice on oral presentation. WESCON's highly successful booklet, "Techniques for Better Talks," will be used extensively, along with instructions on how to prepare and use visual aids.

As another device to provide pace and interest, the committee will include a number of debates by leading technical spokesmen on the program, and is even considering special technical sessions for student-engineers and for women.

Inquiries concerning contributions to the WESCON/1960 technical program should be addressed to Richard G. Leitner, WESCON, 1435 South La Cienega Blvd., Los Angeles 35, Calif.

4th National MIL-E-CON To Be Held This June

More than 4000 of the nation's top engineers, representing the major defense electronic industries as well as the defense agencies, are expected to attend the 4th National Convention on Military Electronics (MIL-E-CON 1960), which will be held again this year in Washington, D. C., on June 27, 28, and 29. This annual meeting is sponsored by the Professional Group on Military Electronics.

Highlighting the convention will be 20 unclassified technical sessions, plus five classified sessions which will be sponsored by the Air Research and Development Command. Topics to be covered include space electronics, guidance and space technology, communications equipment, instrumentation, simulation, and data handling.

At the opening session of the convention on Monday, officers from the three military services will take part in a panel discussion on research and development. Dr. Jerrold R. Zacharias, Professor of Physics at the Massachusetts Institute of Technology, will act as moderator.

Concurrently with the technical sessions, there will be exhibits of the latest in military electronic components and equipment in the exhibit areas of the Sheraton-Park Hotel, headquarters for the convention.

A tentative listing of the technical papers and authors was printed in the May, 1960 issue of the Proceedings.

FCC Asks JTAC to Study Frequency Diversity

The Joint Technical Advisory Committee has agreed to a request by the FCC on December 29, 1959, to make a study of the use of frequency diversity by common carriers. The Commission is now authorizing the use of microwaves in various private radio services and has asked the JTAC for any information of a theoretical or empirical nature which could illuminate the following questions:

1) What relative levels of circuit reliability are reasonably obtainable using a) frequency diversity, b) space and/or polarization diversity, and c) no diversity? (Using the same transmitting and receiving equipment.)

2) What are the general relationships among the parameters affecting the performance of a frequency diversity system, such as frequency separation, transmitted power, bandwidth and hop length?

3) What are the general relationships among the parameters affecting the performance of a space of polarization diversity system, such as spatial separation of transmitting and receiving antennas, power, bandwidth, and hop length?

4) What is the over-all impact on efficient utilization of the radio spectrum of the use of frequency diversity, and under what conditions might such impact, if adverse, be lessened?

5) What are the relative costs of these techniques in terms of equipment installation, real estate, and spectrum utilization? What sacrifices should be made in regard to radio spectrum conservation to accommodate the economic factors in microwave circuits of high reliability?

6) To what extent is the need for frequency or space diversity dependent upon the type of modulation being used; *e.g.*, FM *vs* pulse, etc.? Conversely, how is the effective use of frequency, space or polarization diversity affected by the type of modulation employed?

7) If the answers to the above questions depend upon what portion of the usable microwave spectrum is being considered, kindly analyze and specify the variations.

JTAC Tribute to J. W. McRae

The Joint Technical Advisory Committee passed the following resolution at its meeting on February 18, 1960, as a tribute to the late Dr. James W. McRae:

The Joint Technical Advisory Committee and its sponsors (the IRE and the EIA) wish to express their deep sense of loss at the untimely death of Dr. James W. McRae, member of this Committee. Through his unselfish devotion to the work of his profession and the electronics industry and through his dedication to the complex technical problems relating this industry with the national defense, his contributions were unique.

He will be sorely missed, not only by JTAC, but in the many other activities where his cheerful counsel, keen intellect and broad understanding contributed to our technical progress, national security and welfare.

Air Force MARS Eastern Net Outlines June Programs

The following is the June schedule for the Air Force MARS Eastern Technical Net, operating Sundays, 2 to 4 p.m. EDT, on 3295 kc, 7540 kc, and 15715 kc.

June 5 "Orbiting Satellite Communications," H. Hoffmann, Jr., Chief, Information Processing Branch, Directorate of Communications, Rome Air Dev. Center, USAF.

June 12 "Some Aspects of Extra-Terrestrial Communications," A. Feiner, Chief, Advanced Developments Lab., Rome Air Dev. Center, USAF.

The Air Force MARS Eastern Technical Net adjourns for Summer recess following the June 12th broadcast. Regular programming will resume on September 18th.

TALL TALE FROM TEXAS

A few years after the Battle of the Alamo, a Texan was showing a friend from Oklahoma around the famed battle site.

Everything was preserved just as it had been on the historic day. The donkey still plodded patiently on his treadmill, making the great radar antenna turn round and round.

"What's that?" the man from Oklahoma asked.

"Why anybody knows what that is!" the Texan said. "That's radar. Invented right here in Texas. It can see in the dark, this radar can. You can't make a move without its knowing it, no matter if you're two miles away."*

"If that's what radar is — some ass on a treadmill, goin' nowhere — for something that can see in the dark and you can't get away from — we've had them in Oklahoma for years."

"You've had radars for years?"

"Sure," the Oklahoman said. "Only we call 'em husbands and wives."

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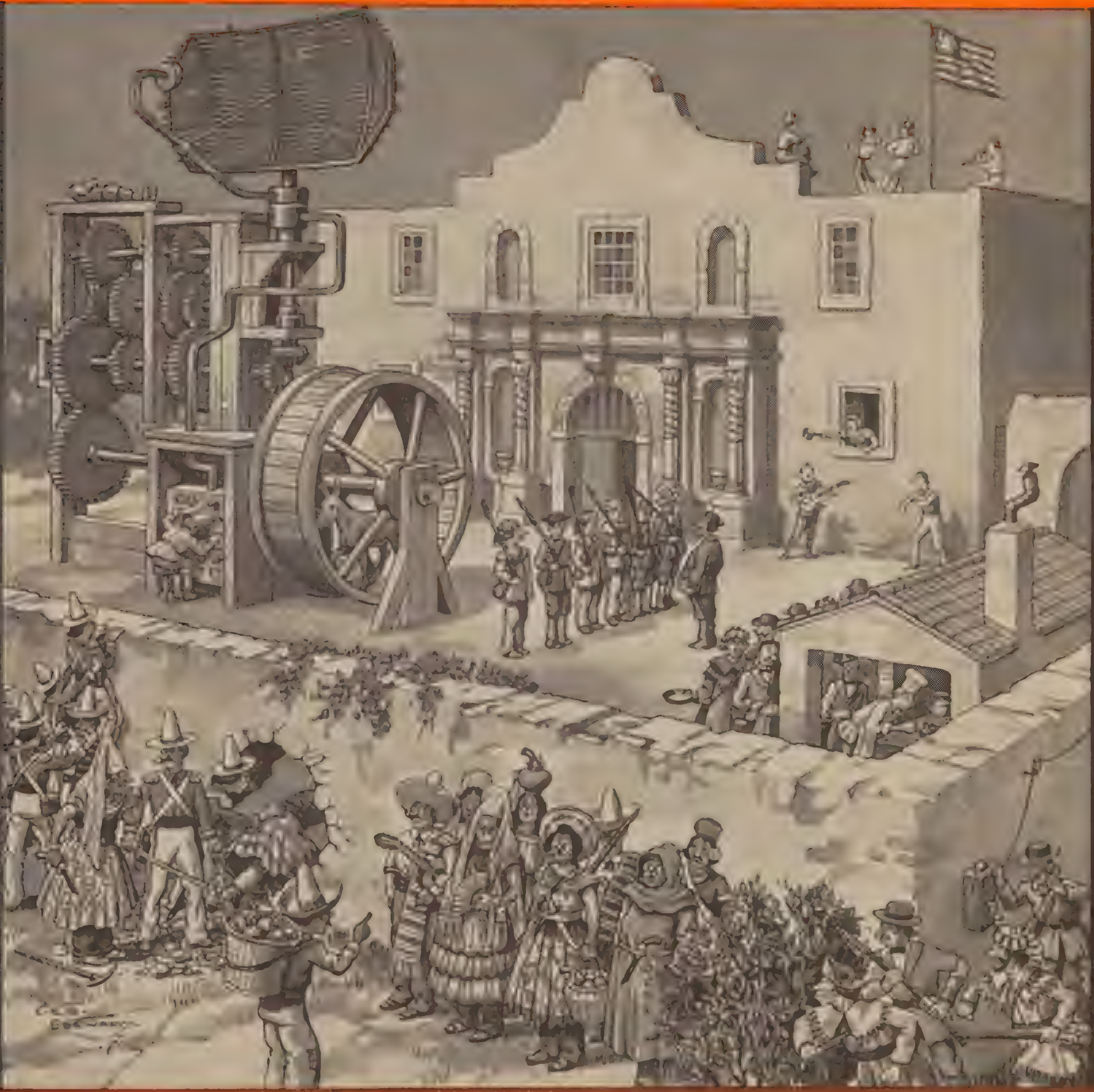

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CALL FOR TECHNICAL PAPERS FOR ELECTRONIC COMPONENTS

The IRE Professional Group on Component Parts is sponsoring a special component parts issue of the PROCEEDINGS OF THE IRE which will appear in May, 1961. The theme of the issue is "Electronic Components—Present and Future." The new and most advanced aspects of the current electronic component art will be covered and important trends will be analyzed with regard to their ability to fulfill equipment and system needs of the future. You are invited to submit manuscripts in keeping with this objective. The following are some suggested fields of interest: Discrete Components, *R*, *L*, *C*, etc. (linear and nonlinear); Functionally Complex Components (integrated, film type, or solid state); Thin Film Components (magnetic, conductive, dielectric, or semiconductor); Components-Systems Integration, Component Reliability, Semi-conductors (as applied to electronic components); Electro-mechanical Devices and Concepts, Microwave Components, Ferroelectric-Ferromagnetic Devices, Square Hysteresis Loop Components, Thermoelectric Power and Devices, Magneto-optics, Cryotrons and Crygenics, Electroluminescence, Memory Devices, Electronic Materials, Processes, Techniques and Analytical Tools (electron beam machining, ultra vacuum techniques, or microfilms); Filter and Delay Lines (electronic, electro-mechanical, or electro-strictive); Switching Devices (mechanical, solid state).

Manuscripts of papers are due by November 1, 1960. Please submit three copies to Vincent J. Kublin, Chairman Components Issue Committee, U. S. Army Signal R & D Lab., Fort Monmouth, N. J. Authors will be notified of selection late in December, 1960.

GORDON RESEARCH CONFERENCES ANNOUNCE 1960 PROGRAM

The Gordon Research Conferences for 1960 will be held from June 13 to September 2 at Colby Junior College, New London, N. H.; New Hampton School, New Hampton, N. H. and Kimball Union Academy, Meriden, N. H.

The conferences were established to stimulate research in universities, research foundations and industrial laboratories. This purpose is achieved by an informal type of meeting consisting of scheduled lectures and discussion groups. Sufficient time is available to stimulate informal discussions among the members of each conference. Meetings are held in the morning and in the evening, Monday through Friday, with the exception of Friday evening. The afternoons are available for recreation, reading or participation in discussion groups as the individual desires. This type of meeting is a valuable means of disseminating information and ideas to an extent that could not be achieved through the usual channels of publication and presentation at scientific meetings. In addition, scientists in related fields become acquainted, and associations may be formed that result in collaboration and cooperative efforts between different laboratories.

It is hoped that each conference will extend the frontiers of science by fostering a free and informal exchange of ideas among persons actively interested in the subjects under discussion. The purpose of the program is to bring experts up to date on the latest developments, to analyze the significance of these developments, to provoke suggestions concerning the underlying theories and profitable methods of approach for making progress. It is not to review the known fields of chemistry and physics.

In order to protect individual rights and to promote discussion, it is an established requirement of each conference that no information presented is to be used without specific authorization of the individual making the contribution, whether in formal presentation or in discussion. Scientific publications are not prepared as emanating from the conferences.

Attendance at the Conferences is by application. Individuals interested in attending the conferences are requested to send their applications to the director at least two months prior to the date of the Conference. All applications must be submitted on the standard application form which may be obtained by writing to the office of the Director. This procedure is important because certain specific information is required in order that a fair and equitable decision on the application may be made. Attendance at each conference is limited to approximately 100 conferees.

The director will submit the names of those requesting authorization to attend to the conference committee for each conference. This committee will review the names and select the members in an effort to distribute the attendance as widely as possible among the various institutions and laboratories represented by the applications. A registration card will be mailed as soon as possible to those selected. Advance registration by mail for each conference is required and registration is completed on receipt of the card and a deposit of $15. (Checks are to be made payable to the Gordon Research Conferences.) The deposit of $15 will be credited against the fixed fee for the Conference if the individual attends the Conference for which he has applied. A registration card not accompanied by the $15 deposit will not be accepted.

The Board of Trustees of the Conferences has established a fixed fee of $100 for resident conferees at each Conference. This fee was established to encourage attendance for the entire Conference and to increase the Special Fund that is available to each Conference Chairman for the purpose of assisting conferees who attend a Conference at total or partial personal expense with their travel or subsistence expenses or with both. This fixed fee will be charged regardless of the time a conferee attends the Conference—that is, for periods of from one to four and one-half days. It is divided as follows: registration fee $40 ($15 for administration and $25 for the Special Fund); room and meals $60 (including gratuities), for five days. An additional charge of $1 per night per person will be made for a room with private bath or for a single room, of which there are only a limited number. These rooms will be assigned in the order that applications are received. An additional charge will also be made for rooms occupied more than five nights.

Members attending a Conference are expected to live at the Conference location because one of the objectives of the Conferences is to provide a place where scientists can get together informally for discussion of scientific research of mutual interest. It is to the advantage of all participants to attend a Conference for the entire week. When special circumstances warrant a request to live elsewhere permission must be obtained from the director. If the request is approved these nonresident conferees will be charged a registration fee of $50.

The fixed fee will cover registration, room (except room with private bath or single room), meals and gratuities for resident conferees. It will not provide for golf, telephone, taxi, laundry, conference photograph, or any other personal expenses.

Conferees living at the Conference location who will pay all or part of the fixed fee as a personal expense may request a reduction of $25 (the amount allotted for special fund) in the fixed fee. Application for this special fee of $75 must be made when the registration card is returned to the Director.

Accommodations are available for wives who wish to accompany their husbands. All such requests should be made at the time the attendance application is submitted because these accommodations, limited in number, will be assigned in the order that specific requests are received. Children twelve years of age and over can be accommodated at the Conferences. Pets are not permitted in the dormitories.

A special fund is provided for by the Board of Trustees from the registration fee. It is made available to the chairman of each conference for the purpose of increasing the participation of research scientists who could not otherwise attend because of financial limitations. Its use is not limited to scientists who have been invited by the chairman to attend a conference in order to present research results. The money is to be used as an assistance fund only and may be used to contribute toward traveling expenses or subsistence expenses at the conference, or both. Total travel and subsistence expenses will not usually be provided.

Requests for attendance at the conferences, or for additional information, should be addressed to W. George Parks, Director, Department of Chemistry, University of Rhode Island, Kingston, R. I. From June 13 to September 2, 1960 mail should be addressed to Colby Junior College, New London, N. H.

AMA DIRECTORS ANNOUNCE DRIVE TO REDUCE INTERFERENCE

The Automobile Manufacturers Association Board of Directors has recommended to U. S. car, truck and bus makers that a concerted effort be made to suppress interference-producing electrical radiation in all motor vehicles, based on new standards established by the Society of Automotive Engineers.

To keep such radio interference from becoming a serious public problem, vehicle manufacturers started control measures under existing SAE standards as early as 1946.

While established practices of shielding and otherwise reducing ignition radiation have largely solved interference problems in ordinary low-frequency radio equipment, the growth of high frequency broadcasting in recent years prompted the need for more thorough suppression. Higher frequencies—

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They are *building block modules*. They are a product of Delco Radio's newly developed, three-dimensional packaging technique. They are used to build light, compact, reliable airborne and special purpose digital computers for missile control. Each module, vacuum encapsulated with epoxy resin, contains up to 35 standard components per cubic inch—averaging more than 50,000 per cubic foot. The modules perform all the standard logic functions. They meet or exceed all MIL-E-5272D (ASG) environmental requirements and will operate over a temperature range of −55°C to +71°C. They can be assembled in groups on printed circuit boards. There are 10 basic types and 15 variations of Delco Building Block Modules. With them, Delco Radio can quickly and easily build a compact, reliable computer for airborne guidance or any other military application. For complete details, write to our Sales Department. *Physicists and electronic engineers: Join Delco Radio's search for new and better products through Solid State Physics.*

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Division of General Motors • Kokomo, Indiana such as those used in television, FM radio, and radio-telephone broadcasting—are more sensitive to electrical interference.

EJCC Proceedings Now Available

Proceedings of the 1959 Eastern Joint Computer Conference, a 260-page volume containing all 31 papers prepared for presentation at Boston, Mass., last December, are now available. The papers cover a wide range of subjects of special interest to everyone concerned with the development and manufacture of computers and with their use in scientific and business applications. Hundreds of illustrations and complete transcripts of the discussions held in connection with each paper are also included in this review of current advances in computer technology. Copies at $3.00 each may be ordered from the Institute of Radio Engineers, 1 East 79th St., New York 21, N. Y.; the American Institute of Electrical Engineers, 33 West 39th St., New York 18, N. Y.; or the Association for Computing Machinery, 2 East 63rd St., New York 21, N. Y. Copies of the Proceedings of prior Joint Computer Conferences are also available in limited quantities from the same organizations.

Acoustical Society To Index Journals of Past Decade

The third decennial index of *The Journal of the Acoustical Society of America*, a work reflecting the accelerated program of acoustical research in the past decade, will be published late this summer.

The index will contain the following sections:

1) Author and subject indexes to papers published in the JASA during the period of 1949–1958 inclusive.
2) Author and subject indexes to contemporary papers on acoustics published in many other journals and listed in the JASA during the period 1949–1958 (approximately 13,500 references).
3) Inventor, subject, and numerical indexes to acoustical patents reviewed in the JASA during the period 1949–1958 (approximately 4000 patents).

There will be only one printing of this 1100 page index. Inquiries concerning price and other information should be addressed to the Acoustical Society of America, 335 E. 45 St., New York 17, N. Y.

Fourth Symposium on Global Communications Calls for Papers

The Fourth Global Communications Symposium, co-sponsored by the IRE Professional Group on Communications Systems and the U.S.A. Signal Corps in honor of its 100th Anniversary, will be held August 1–3, 1960 at the Statler Hilton Hotel, Washington, D. C. Deadline for abstracts of papers to be submitted to the Symposium is May 16, 1960. All communications should be addressed to Ralph L. Clark, c/o Office of Director of Defense Research and Engineering, Washington 25, D. C.

1960 WESCON Names Committee Chairmen

Electronics industry executives who will guide the preparations for WESCON/1960 as chairmen of 14 working committees have been named by the board of directors.

WESCON, scheduled August 23 through 26 in Los Angeles' new Sports Arena, will require the combined efforts of about 30 volunteer committeemen and women in addition to its permanent management staff. An estimated 35,000 persons will be registered for attendance at the four-day trade show and technical convention, and applications for exhibit space have been sent to about 4000 electronics firms.

Joint sponsorship of the big event, by the Western Electronic Manufacturers Association and the Los Angeles and San Francisco sections representing the Seventh Region of the IRE, is reflected in committee work as it is in WESCON'S policy-making and executive groups.

Executive committee members include Hugh P. Moore, chairman (Lerco Electronics); Walter E. Peterson, chairman of the WESCON board (Micro Gee Products); Bruce S. Angwin, convention director (General Electric); Donald C. Duncan, show director; and Don Larson, WESCON manager.

Committee chairmen and vice chairmen, and their areas of responsibility are:

All-Industry Luncheon: Edward C. Bertolet (Behlman Engineering) and E. H. Lockhart (Radiatronics).

Cocktail Party: William J. Miller (Burton Manufacturing) and Robert L. Boniface (Neely Enterprises).

Distributor Conference: W. Bert Knight (W. Bert Knight Co.) and R. V. Weatherford (R. V. Weatherford Co.).

Exhibits: Ernest Clover (Triad Transformer) and Herb Becker (Herb Becker Co.).

Facilities: Donald N. Montgomery (Aeronutronic) and Duane Wood (Lockheed Aircraft Service).

Field Trips: A. N. Curtiss (RCA) and Eugene M. Knight (Space Technology Labs.).

Future Engineers: Joel H. Axe (Ramo-Wooldridge) and Col. Frank J. Shannon, Sr., USAF (Ret.) (Packard Bell).

Hospitality: Burgess Dempster (Electronic Engineering) and John J. Guarrera (Burton Manufacturing).

Industrial Design: Kenneth J. Slee (Librascope) and Robert C. Saunders, Jr. (Benson-Lehner).

Public Relations: Willard B. Gregory (Beckman Instruments) and Richard L. Paullus (Electronics Investment Management Corp.).

Registration: G. Goldenstern (Hoffman Electronics) and Harry J. Delaney (Hughes Aircraft).

Technical Program: Richard G. Leitner (System Development Corp.) and Harper Q. North (Pacific Semiconductors).

Visitors Services: Al J. Rissi and C. T. Kierulff (Kierulff Electronics).

Women's Activities: Mrs. Jeff Montgomery and Mrs. Don Larson.

WESCON'S Industrial Design competition, premiered last year in San Francisco and received enthusiastically, will be greatly expanded in 1960, according to Mr. Larson. Another traditional WESCON feature, the Future Engineers competition, will also have wider representation from among student-engineers throughout the West.

The Facilities Committee, replacing the Arrangements Committee, serves all other committees in meeting their needs for equipment, signs, furniture, telephone service, and other materials and services; the Hospitality Committee, a new committee, is charged with making all arrangements for WESCON'S many special guests.

Professional Group News

At its meeting on April 21, 1960 the IRE Executive Committee approved the following new Chapters: Joint PG on **Antennas and Propagation and Microwave Theory and Techniques**—Orange Belt Chapter; PG on **Component Parts**—Omaha-Lincoln Chapter; and PG on **Engineering Writing and Speech**—Philadelphia Chapter.

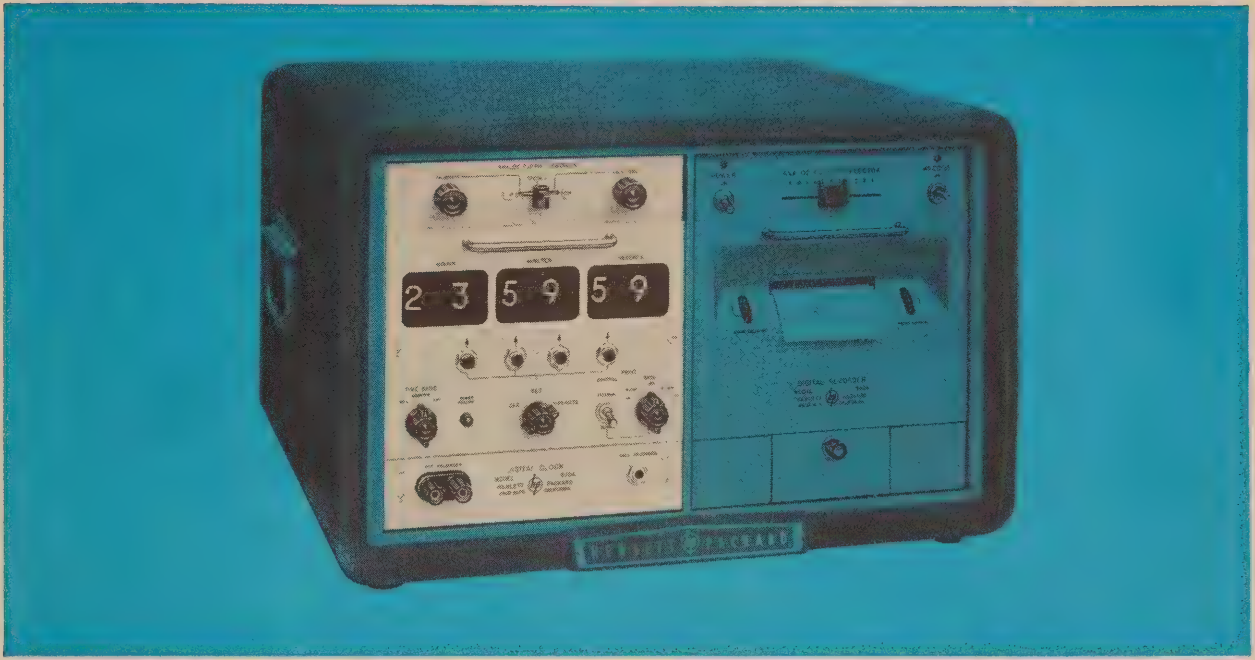
Obituary

Frank A. Hinners (A'12–M'15–F'26) (L), a Charter Member of the IRE, died recently at the age of 66.

Born February 19, 1894 in New York, N. Y., he worked for North American Wireless Corporation from 1910 to 1911. After this he worked at the National Electric Signaling Company, as assistant to Emil J. Simon at the College of the City of New York and Bush Terminal, and later he was employed as a engineer at the Garwood Electric Company. In 1913 he again became an assistant to Mr. Simon at the Wireless Improvement Company, and in September of that year he began attending classes at Pratt Institute, at the same time remaining in the employment of the same company. In 1914 he became an engineer for the Wireless Specialty Apparatus Company, and he remained with them after his graduation from Pratt in 1915, having received the Certificate of Applied Electricity. In 1917 he joined the Sperry Gyroscope Company as a radio engineer, and later that year he became associated with the E. J. Simon Company, where he was made responsible for the development of the Simon 1-kw Transmitter. He later helped to found his own company, the King Hinners Radio Co., of which he was President and Chief Engineer. Subsequently he was employed as Vice President in charge of engineering at the Air King Products Co. and Jewell Radio Corp. In 1952 he joined in establishing the Hinners-Galenek Radio Corp., of which he was President at the time of his death.

Mr. Hinners was one of the founders, and the first vice president of the DeForest Pioneers, organized by the coworkers of Dr. Lee DeForest. He was one of the forty-six charter members of the IRE; he had been a charter member of the Wireless Institute, one of the organizations which merged to form the IRE in 1912. Those Charter Members who are still active in the Institute of Radio Engineers are Dr. Lee DeForest, J. V. L. Hogan, Jr., A. F. Van Dyck, P. B. Collinson, Lloyd Espenschied, Alfred N. Goldsmith and Emil J. Simon.

NEW CLOCKS FOR hp DIGITAL RECORDERS



add time-of-day to recorded data
control taking of readings
fit in Digital Recorder cabinet
available for field installation

New hp 570A and 571B Digital Clocks mount in the left-hand side of hp 560A and 561B Digital Recorders, respectively. The clocks may be installed in the field, and fit either in cabinet arrangement, as shown, or into a combined Recorder-Clock rack mount arrangement only 10½" high.

Time appears as a 23 hour, 59 minute, 59 second presentation (12-hour clocks are available on special order). Display is by long-life, in-line indicator tubes. All time digits are available for printing.

Two operating modes provide utmost usefulness. In the first mode, hp or Dymec Digital Counters, Digital Voltmeters or other external equipment control print rate; time being printed simultaneously with other data. In the second mode, for tests where less frequent readings are desired, the Digital Clocks control the timing of readings. A front panel control selects reading rates of 1 per second, 6 per minute, 1 per minute, 6 per hour or 1 per hour.

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SPECIFICATIONS

Indication: Six in-line long-life digital display tubes. Indication to 23 hrs., 59 min., 59 sec.

Time Base: Ac line, 1 pps from counter, or external 1 pps.

Accuracy: Time base accuracy + 0, — 1 second.

Print Control: Front panel control selects CLOCK or EXTERNAL control mode. PRINT RATE of 1 sec., 6/min., 1/min., 6/hr., 1/hr. also chosen on front panel control.

Output: Six time digits for time recording. Holdoff signals for hp, Dymec counters.

Power Interruption Alarm: Front panel warning light.

Analog Output: 570A retains analog output of 560A.

Prices: hp 570A (fits hp 560A/AR) $1,050.00; hp 571B (fits hp 561B/BR) $950.00.

Data subject to change without notice.
Prices f.o.b. factory.

Call your hp representative for demonstration

Chicago Spring Conference on Broadcast and Television Receivers

GRAEMERE HOTEL, CHICAGO, ILL., JUNE 20 AND 21, 1960

Monday Morning, June 20

"Some Color Slides and Color TV Experiments Using the Land Technique," *Dr. W. L. Hughes, Iowa State Univ., Ames.*

"A Survey of Tunnel Diode Application," *E. Gottlieb, General Electric Co., Syracuse, N. Y.*

"Transistorized Deflection Circuits for 110° Picture Tubes," *G. W. Fyler, G. Strachanow and R. L. Sager, Zenith Radio Corp., Chicago, Ill.*

"Transistorized FM and TV Limiter Design and Performance," *C. R. Gray and T. C. Lawson, Philco Corp., Lansdale, Pa.*

Monday Afternoon

"A New Wide Angle Deflection System and Picture Tube," *R. A. Bloomsburg, J. Pietrolewicz, and J. W. Snyder, Philco Corp., Philadelphia, Pa.*

"A Low Heater Power Cathode Ray Tube," *H. E. Smithgall, Sylvania Electric Products, Inc., Seneca Falls, N. Y.*

"Scan Magnification in TV Picture Tubes," *W. F. Niklas and P. J. Dolon, Rauland Corp., Chicago, Ill.*

"Electrostatic Scan Magnifier," *F. M. Bruno, H. Schmaltz, Tung-Sol Electric, Inc., East Orange, N. J.*

"A Survey of Unconventional Flat Picture Tubes," *Dr. E. G. Ramberg, RCA Labs., Princeton, N. J.*

"Panel Discussions on New Developments in Picture Tubes," Chairman: *Dr. R. Adler, Zenith Radio Corp.;* Members: *N. Parker, Motorola; Z. Wiencek, Warwick, Mfg.; C. Torsch, Rola Corp.; and others to be named.*

Tuesday Morning, June 21

"A Survey of Japanese TV Receivers," *Dr. M. Goldstein, American Inst. of Engineering, Chicago, Ill.*

"Development and Design of a New Ultrasonic Transducer for TV Remote Control," *J. A. Cunningham, Admiral Corp., Chicago, Ill.*

"A Pneumatic Ultrasonic Transmitter for a Low-Cost Remote Control," *P. Tappan, A. Vaccara and L. Babcock, Warwick Mfg. Corp., Chicago, Ill.*

"A New TV Remote Control Package, Transistorized for Compactness," *R. Wolff and M. Marks, Admiral Corp., Chicago, Ill.*

"A High Performance Transistor Output Circuit," *R. C. Graham, RCA, Camden, N. J.*

Tuesday Afternoon

"Unique Design Considerations for Transistorized TV," *L. J. Mattingly, Motorola, Inc., Chicago, Ill.*

"A Low Noise VHF Tuner Using a Nuvistor Triode RF Amplifier," *G. C. Hermeling, RCA Victor, Camden, N. J.*

"Transistorized TV Tuner Having a Noise Figure of Less Than 4.5 db," *F. J. Kitty, C. D. Simmons, and S. W. Sickles, Philco Corp. (Div. of Gen. Instruments), Lansdale, Pa.*

"A New Four Tube Full Performance A.M. Superhet Receiver," *W. J. Sember, Sylvania Electric Products, Chickopee, Mass.; H. P. Mayberry, Sylvania Electronic Tubes, Emporium, Pa.*

"Some Design Aspects of Automatic Gain Control for TV Receivers," *P. H. Van Alrooy, Zenith Radio Corp., Chicago, Ill.*

Alternate Paper

"TV Studio Quality Sweep Linearity with High Efficiency," *C. E. Torsch, Rola Corp.*

1960 Conference on Standards and Electronic Measurements

NATIONAL BUREAU OF STANDARDS BOULDER LABS., BOULDER, COLO., JUNE 22–24, 1960

Wednesday Morning, June 22

Session 1.—Current and Future Problems in Standards and Electronic Measurements

Chairman: *L. B. Wilson, Sperry Gyroscope Co., Great Neck, N. Y.*

Welcoming Speech, *F. W. Brown, Director of the Boulder Labs., National Bureau of Standards, Boulder, Colo.*

"A New Space Age Challenge—Electronic Standards and Measurements," *L. B. Wilson, Sperry Gyroscope Co., Great Neck, N. Y.*

"Calibration Requirements of Aerospace Vehicles," *Col. R. F. Stolle, Wright-Patterson Air Force Base, Ohio.*

"Effect of Tracking Accuracy Requirements on Design of Minitrack Satellite Tracking System," *J. H. Berbert, Goddard Space Flight Center, Washington, D. C.*

"Current Notes on Problems in Standards and Electronic Measurements—DEW Line," *W. G. Donaldson, Federal Electric Corp., Paramus, N. J.*

"The Nation's Electronic Standardization Program: Where Do We Now Stand?" *H. W. Lance, National Bureau of Standards, Boulder, Colo.*

"Propagation of Error in a Chain of Standards," *A. G. McNish, National Bureau of Standards, Washington, D. C.*

"An Analysis of the Accumulated Error in a Hierarchy of Calibrations," *E. L. Crow, National Bureau of Standards, Boulder, Colo.*

"Vendor Calibration Program Coordination and Control," *E. Peebles, Lockheed Aircraft Corp., Sunnyvale, Calif.*

Wednesday Afternoon

Session 2—Frequency and Time Standards

Chairman: *R. A. Sykes, Bell Telephone Labs., North Andover, Mass.*

Status Report, *F. G. Merrill, Bell Telephone Labs., Murray Hill, N. J.*

"Atomic Beam Frequency Standards," *R. Mockler, R. Beehler, C. Snider and L. Fey, National Bureau of Standards, Boulder, Colo.*

"A Prototype Rubidium Vapor Frequency Standard," *R. J. Carpenter, E. C. Beaty, P. L. Bender, S. Saito, and R. O. Stone, National Bureau of Standards, Washington, D. C.*

"Crystal Controlled Frequency Standards—Latest Advances for Long Term Stability," *T. C. Anderson and F. G. Merrill, Bell Telephone Labs., Murray Hill, N. J.*

"Miniature Transistorized Crystal Controlled Precision Oscillators," *W. L. Smith, Bell Telephone Labs., Whippany, N. J.*

"The Power Spectrum and Its Importance in Precise Frequency Measurements," *J. Barnes and R. Mockler, National Bureau of Standards, Boulder, Colo.*

"Time and Frequency Synchronization of Navy VLF Transmissions," *R. R. Stone, Jr., U. S. Naval Research Lab., Washington, D. C., and W. Markowitz and R. Glenn, U. S. Naval Observatory, Washington, D. C.*

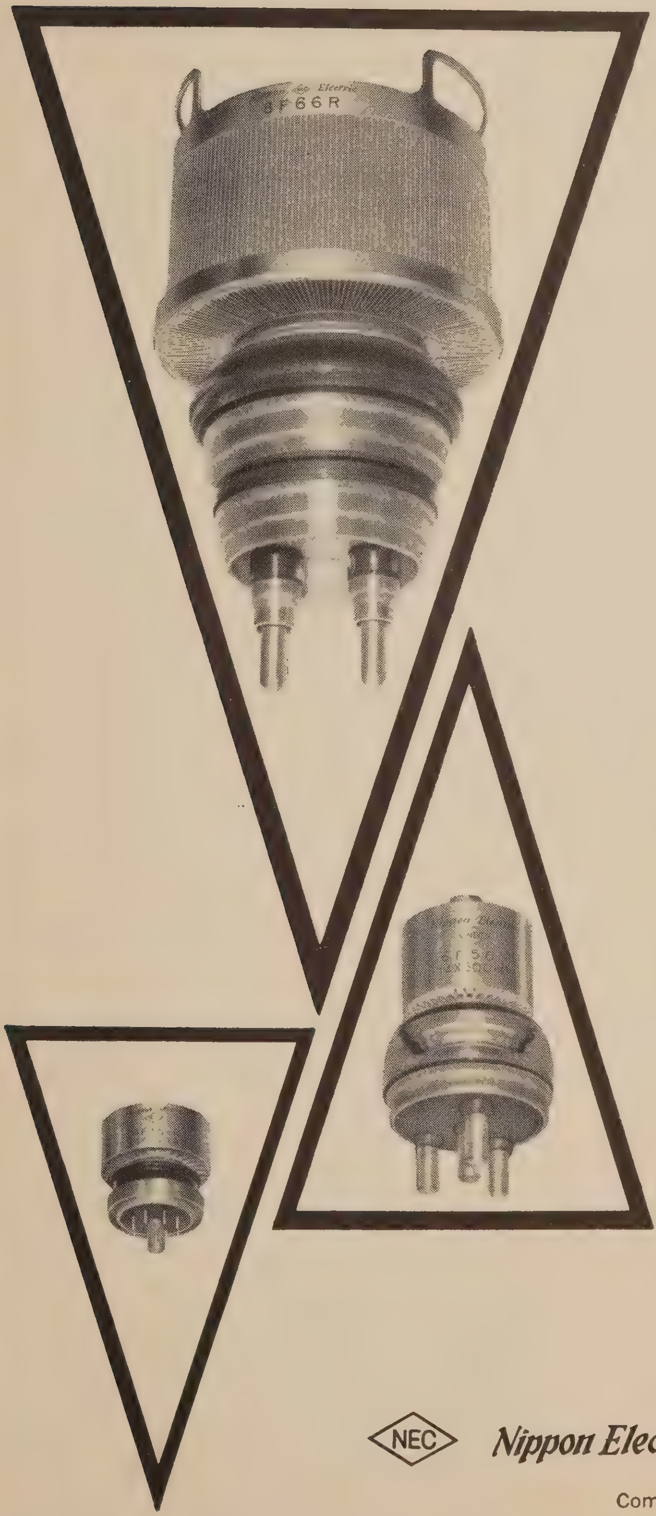
Thursday Morning, June 23

Session 3—Methods of Measurement for Materials

Chairman: *J. L. Dalke, National Bureau*

Reliable NEC replacement tubes

VHF beam power tetrodes



Each of the following NEC tubes is a direct replacement under all circumstances for the corresponding type.

NEC type	Type To Be Replaced	Cathode/ Filament Volts	Grid-Screen Mu-Factor	Max. Plate Ratings	
				Volts (D.C.)	Dissipation (Watts)
4F15R	4X150A	6	5	1,250	150
6F50R	4X500A	5	6.2	4,000	500
8F66R	6,166	5	10	6,000	10,000

Production of high-power transmitting tubes began at NEC in 1933. A number of "firsts" marked these early years: 1933, first 15 KW short-wave transmitter tube; 1934, first 100 KW standard broadcast tube; 1938, first 50 KW short-wave transmitter tube. In recent years, NEC has been following designs of U.S. Manufactures and concentrating on improving tube life.

The most important improvements have been a new doped-nickel cathode material with high emission at low oxide evaporation rate, and non-sag thoriated tungsten filament material which has completely eliminated filament-grid shorts. NEC considers the life characteristic of its electron tubes to be among the most favorable in the industry.

NEC *Nippon Electric Company Limited* Tokyo, Japan

Components / Systems

of Standards, Boulder, Colo.

"Determination of Nonlinear Characteristics of Ferroelectric Ceramics," *P. N. Wolfe, Westinghouse Research Labs., Pittsburgh, Pa.*

"Measurement of the Wave-Propagation Properties of Plasma in the Microwave Region," *F. J. Tischer, Ohio State Univ., Columbus, Ohio.*

"Standards and Measurements of Microwave Skin Depth, Conductivity, Surface Impedance, and Q," *H. E. Bussey, National Bureau of Standards, Boulder, Colo.*

"The Measurement of Volume Resistivity of Semiconductor Material at X Band Frequencies," *J. R. Seifert and G. L. Allerton, Western Electric Co., Allentown, Pa.*

"A Radio Frequency Permittimeter," *R. C. Powell and A. L. Rasmussen, National Bureau of Standards, Boulder, Colo.*

"The Measurement of Microwave Resistivity by Eddy Current Loss in Small Spheres," *T. Kohane, Raytheon Co., Waltham, Mass.*

"Measurement of Microwave Ferrites at High Signal Levels," *J. F. Ollom and W. H. von Aulock, Bell Telephone Labs., Inc., Whippany, N. J.*

"A Vibrating Sample Magnetometer," *N. V. Frederick, National Bureau of Standards, Boulder, Colo.*

Thursday Afternoon

Session 4—Microwave Standards and Calibrations

Chairman: *M. Magid, FXR Inc., Woodside, N. Y.*

"Rapid Broad Band Directional Coupler Directivity Measurements," *M. F. Bottjer, T. Mukaihata, and H. J. Tondreau, Hughes Aircraft Co., Culver City, Calif.*

"A Transfer Instrument for the Intercomparison of Microwave Power Meters," *G. F. Engen, National Bureau of Standards, Boulder, Colo.*

"Precision Measurements of Temperatures of Microwave Noise Sources," *A. J. Estin, C. L. Trembath, and J. S. Wells, National Bureau of Standards, Boulder, Colo.*

"A Waveguide Spark Gap as a Standard for Microwave High Voltages," *R. D. Wengenroth, Wheeler Labs., Smithtown, N. Y.*

"A Modulated Subcarrier Technique of Measuring Microwave Phase Shifts," *G. E. Schafer, National Bureau of Standards, Boulder, Colo.*

"Measurement of Reflections and Losses of Waveguide Joints and Connectors Using Microwave Reflectometer Techniques," *R. W. Beatty, and G. F. Engen, National Bureau of Standards, Boulder, Colo.*

Friday Morning, June 24

Session 5—Direct-Current and Low-Frequency Standards and Calibrations

Chairman: *W. G. Amey, Leeds and Northrop Co., Philadelphia, Pa.*

"An Investigation of Long Term Stability of Zener Voltage References," *R. P. Baker, Sandia Corp., Albuquerque, N. M., and J. Nagy, Jr., Weston Instruments Div. of Daystrom, Inc., Newark, N. J.*

"A Standard Current Transformer and Comparison Method—a Basis for Establishing Ratios of Currents at Audio Frequencies," *B. L. Dunfee, National Bureau of Standards, Washington, D. C.*

"Calibration of a Kelvin-Varley Standard Divider," *M. Morgan and J. Riley, Electro Measurements, Inc., Portland, Ore.*

"The Precision Measurement of Transformer Ratios," *R. D. Cutkosky and J. Q. Shields, National Bureau of Standards, Washington, D. C.*

"Ratio Transformer Bridge for Standardization of Inductors and Capacitors," *D. L. Hillhouse and H. W. Kline, General Electric Co., Schenectady, N. Y.*

"A 0 to 180 Degree Phase Angle Master Standard for 400 c/s," *J. H. Park and H. N. Cones, National Bureau of Standards, Washington, D. C.*

Friday Afternoon

Session 6—High Frequency Standards and Calibrations

Chairman: *R. A. Soderman, General Radio Co., West Concord, Mass.*

"Admittance Standardization and Measurement in Relation to Coaxial Systems," *D. Woods, Ministry of Aviation, London, Eng.*

"A Precision Attenuation Calibration System," *C. M. Allred and C. C. Cook, National Bureau of Standards, Boulder, Colo.*

"Techniques and Errors in High-Frequency Voltage Calibrations," *E. Uiga and W. F. White, Ballantine Labs., Boonton, N. J.*

"A Precision RF Power Transfer Standard," *P. A. Hudson, National Bureau of Standards, Boulder, Colo.*

"A Subtle Error in R. F. Power Measurements," *S. J. Raff and G. U. Sorger, Weinschel Engineering, Kensington, Md.*

"Temperature Compensated Microwatt Power Meter," *E. E. Aslan, FXR, Inc., Woodside, N. Y.*

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An achievement in defense electronics

NEW THERMOPLASTIC RECORDING DISPLAY ACHIEVES

Detection to Projection in Less than a Second

Large-screen display of radar signals can be recorded and projected in less than a second. This advanced technique in information display is an example of one application of the new thermoplastic recording system developed by General Electric.

The grainless, thermoplastic film eliminates processing delays and permits, with higher resolution, much greater enlargement than is practical with high-speed photographic film. Target delineation is also significantly improved by optical filtering used to increase the signal-to-noise ratio.

Now undergoing final development in General Electric's Electronics Laboratory, the "thermoplastic display" is expected to find maximum application in the high-speed radar systems of the future. 176-03

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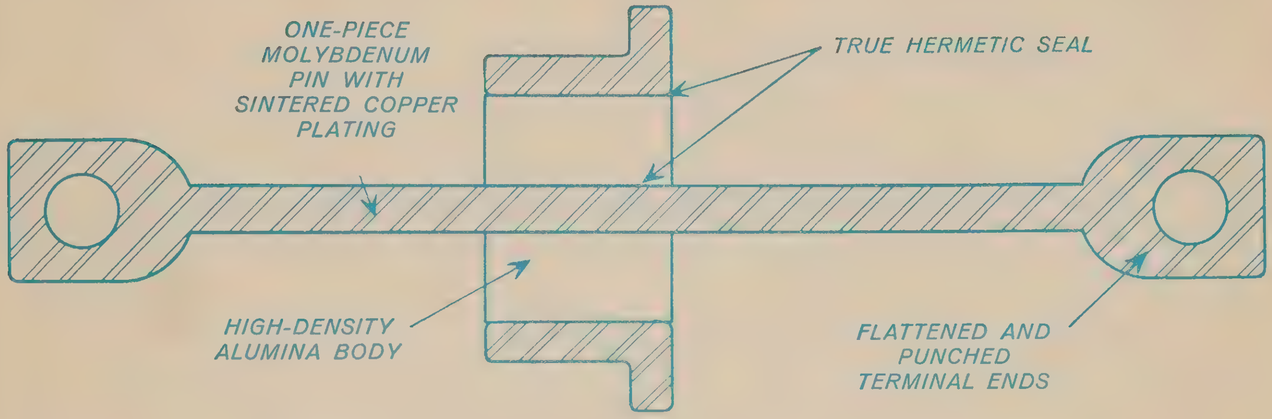
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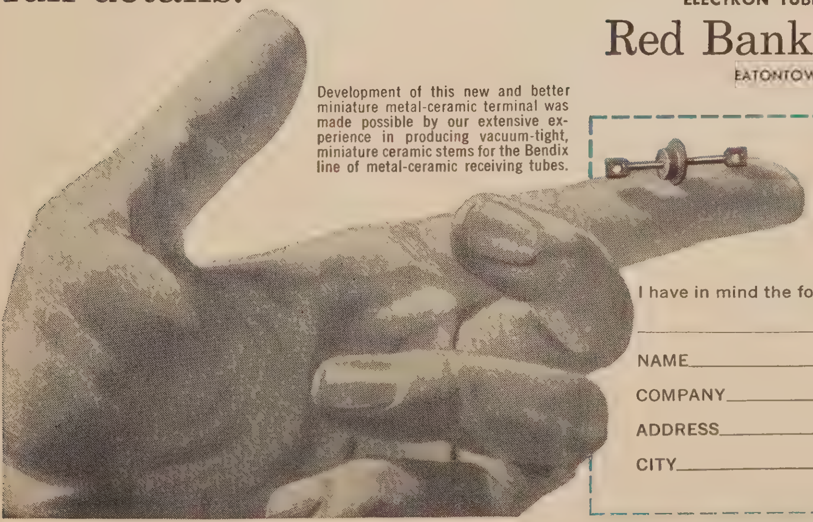

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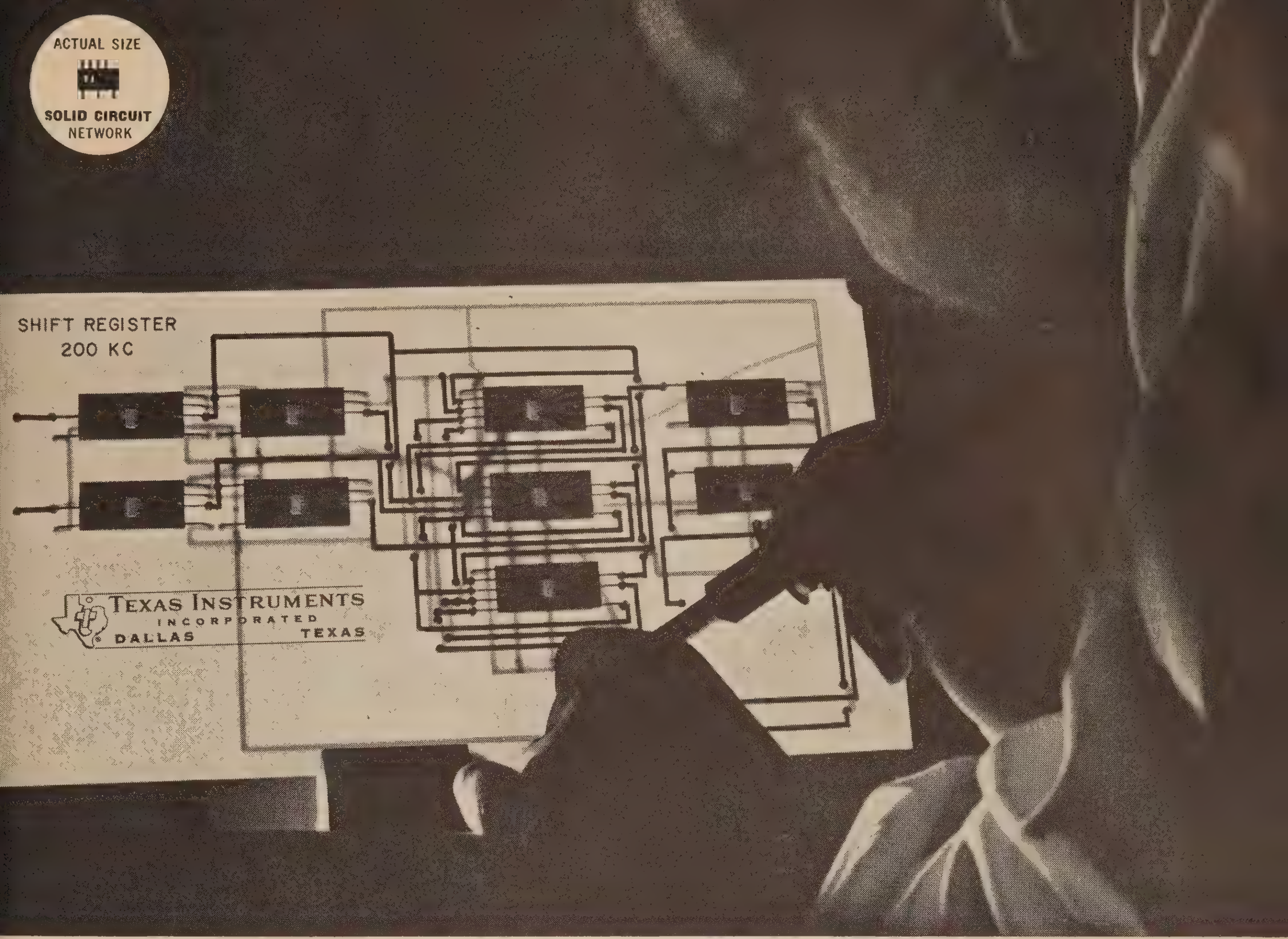

I is now developing revolutionary missile electronics using SOLID CIRCUIT* semiconductor networks

n 1959, four years ahead of industry expectations, Texas nstruments introduced *Solid Circuit* semiconductor net-orks . . . a new concept for harnessing the functions of a omplete circuit in a single crystal silicon wafer no larger han the head of a match.

ow, system designers in TI's Apparatus division are pplying this concept to digital flight control problems — nd the result is minimum 30-to-one size reduction over he highest-density packaging previously available. Equally mportant is an 80% reduction in the number of solder oints — a major cause of electronic equipment failure. pparatus division experience in this new concept indicates hat nearly half of today's military electronics, ground or irborne systems, can make practical, beneficial use of *olid Circuit* networks.

ther reliability gains attributed to this new design concept volve from simplified production, test and process control. quipment fabrication steps already have been reduced to ne-tenth those needed for the same circuit functions using onventional components. Where unprecedented long-term eliability is required such as in space flight, the weight and space consumed by conventional components can now be diverted to circuit redundancy and "self-healing" techniques. And in missile/space vehicle design these new space and weight savings mean that fuel load can be increased without displacing valuable instrumentation.

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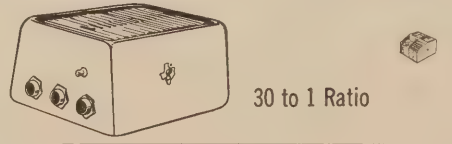

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ULTRA-BROADBAND COVERAGE

**2,000 to 75,000 mc
in a single unit**

Ⓐ **External Mixer.** May be located at or near antenna, any distance up to 75 feet from receiver.

Ⓑ **Flexible cable connects mixer to receiver.** Eliminates cumbersome rigid waveguide.

Ⓒ **Internal electronic 1000 cps sweep** allows direct operation into any standard make AC antenna pattern recorder.

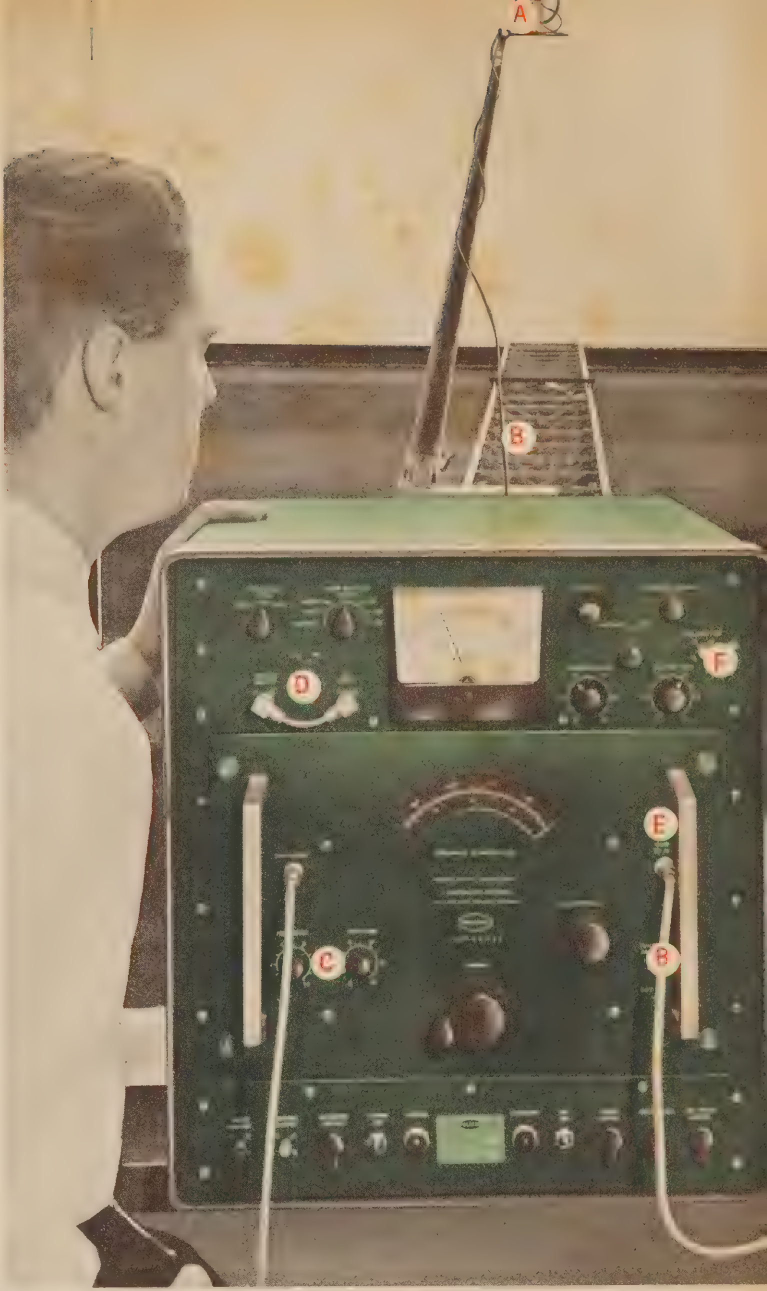
Ⓓ **CW, AM, FM and pulse reception.**

Ⓔ **Sensitivity.**

2 kmc to 10 kmc	—85 dbm.
10 kmc to 35 kmc	—80 dmb.
35 kmc to 75 kmc	—70 dbm.

Ⓕ **Linearity** maintained over 40 db dynamic range.

The Model RW-T is another example of the versatility of the well known Polarad Model R Microwave Receivers. The RW-T is excellent to measure antenna gain, pattern, minor lobes, front-to-back ratio, SWR and bandwidth.



Model RW-T Microwave receiver being used to make antenna pattern measurements on Polarad range.

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☐ Model RW-T Antenna Pattern Receiver

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My application is________________________

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COMPACT MICROWAVE POWER SOURCE

1,050 to 11,000 mc 4 PLUG-IN UNITS

Model KSS Power Source being used to make antenna pattern measurements on Polarad Antenna Range. Can also be used for minor lobes, front to back ratio, SWR and gain measurements.

The new Polarad Model KSS features an advanced modulator design that provides CW, FM and internal square wave (10 to 10,000 pps). External pulse capabilities permit rise times to 0.15 μsec. The unit has an adjustable attenuator and low incidental AM and FM at relatively high power.

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28.4.2 DEFINITIONS AND LETTER SYMBOLS OF SEMICONDUCTORS

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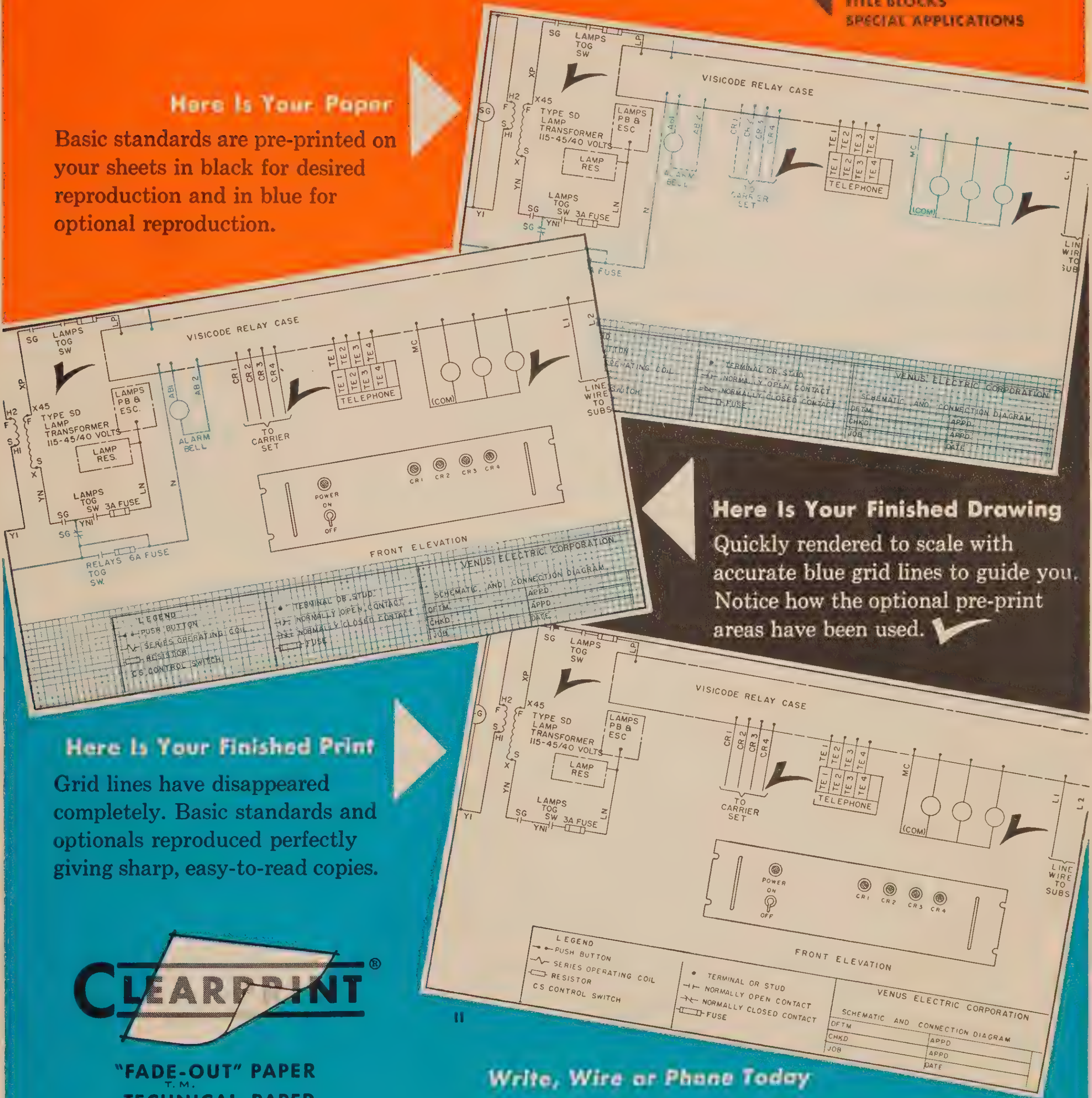
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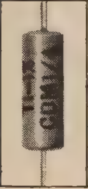

TI type number	wattage rating watts	MIL designation	standard resistance ranges	max. recommended voltage volts
CDM⅛	⅛	RN60B	10 Ohm-1 Meg	350
CDM¼	¼	RN65B	10 Ohm-1 Meg	500
CDM½	½	RN70B	10 Ohm-5 Meg	750
CDM 1	1	RN75B	10 Ohm-10 Meg	1000
CDM 2	2	RN80B	50 Ohm-50 Meg	2000

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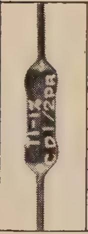

TI type number	wattage rating watts	MIL designation	standard resistance ranges	max. recommended voltage volts
CD⅛R	⅛	—	10 Ohm-1 Meg	350
CD¼R	¼	RN10X	10 Ohm-1 Meg	500
CD½PR	½	RN15X	10 Ohm-3 Meg	650
CD½MR	½	RN20X	10 Ohm-5 Meg	750
CD½SR	½	—	50 Ohm-10 Meg	850
CD1R	1	RN25X	10 Ohm-10 Meg	1000
CD2R	2	RN30X	50 Ohm-50 Meg	2000

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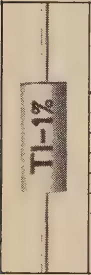


TI type number	wattage rating watts	MIL designation	standard resistance ranges	max. recommended voltage volts
CDH⅛M	⅛	—	10 Ohm-500K	250
CDH⅛	⅛	RN60B	10 Ohm-1 Meg	350
CDH¼	¼	RN65B	10 Ohm-1 Meg	500
CDH½P	½	—	10 Ohm-3 Meg	650
CDH½A	½	RN65B	10 Ohm-3 Meg	650
CDH½M	½	RN70B	10 Ohm-5 Meg	750
CDH½S	½	—	50 Ohm-10 Meg	850
CDH 1	1	RN75B	10 Ohm-10 Meg	1000
CDH 2	2	RN80B	50 Ohm-50 Meg	2000

†All values available in 1% tolerance; nominal lead length 1.5 in.

sensistor* SILICON RESISTORS

Standard available resistances @ 25° C:
68, 82, 100, 120, 150, 180, 220, 270, 330, 390, 470, 500, 560, 680, 820, 1000, 1200, 1500, 1800 ohms.‡

Type No.	Wattage Rating	Body Dimensions		Average Temperature Coefficient	Resistance Tolerance
	W	Length	Diameter	%/°C	%
TM ¼	¼	0.585″	0.200″	+0.7	±10
TM ⅛	⅛	0.406″	0.140″	+0.7	±10
TC⅛	⅛	TO—5	Transistor	+0.7	±10

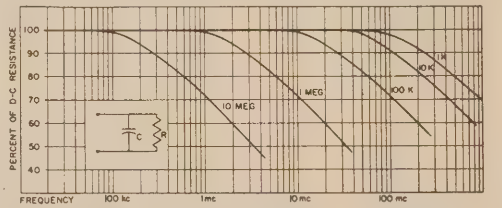
* TRADEMARK OF TEXAS INSTRUMENTS INCORPORATED
‡ Other resistance values and tolerances available on special order

For a more detailed discussion of this subject, contact your nearest TI sales office for a copy of "High-Frequency Characteristics of Precision Film Resistors."

In high frequency applications, precision film resistors are superior to composition or wirewound resistors; skin effect of the thin film is negligible.

OHMIC VALUE vs FREQUENCY

Precision film resistors of a given physical size have the same distributed capacitances regardless of their ohmic value. As the frequency increases, the shunting effect of the distributed capacitance causes the effective parallel resistance to decrease. The reactance of the stray capacitance becomes a relatively good shunt when it approximates the ohmic value of the resistor. The smaller the ohmic value of a precision film resistor (for a given physical size), the higher its usable frequency range.



HIGH FREQUENCY RESISTANCE OF PRECISION FILM RESISTORS

INDUCTANCE CONSIDERATIONS

The inductance caused by helixing the higher value resistors is negligible throughout the "useful" range of frequencies at which the resistance is greater than 60% of its d-c value.

When resistors under 500 ohms are measured using high frequency meters, the reactive component of the equivalent parallel circuit appears inductive because of lead and binding post inductance. However, the resistor itself is capacitive.

TI TYPE	SIZE (WATT RATING)				
	⅛	¼	½	1	2
MIL-LINE (CD)	0.2	0.1	0.25	0.5	0.6
MOLDED (CDM)	0.3	0.25	0.45	0.7	0.7
HERMETICALLY SEALED (CDH)	0.3	0.25	0.45	0.75	0.8

CAPACITANCE IN $\mu\mu$f OF TI PRECISION FILM RESISTORS

CAPACITANCE CONSIDERATIONS

The average measured capacitance of Texas Instruments Precision Film Resistors is determined primarily by the end cap-to-cap capacitance which is proportional to the dielectric constant of the core and encapsulating material.

MOUNTING

Precision film resistors of 200 ohms or less perform satisfactorily at 5000 mc and higher if placed in a well-designed coaxial mount. A coaxial mount constructed from a standard UG-18B/U Type N plug can be used effectively. In conventional terminals, correct mounting of the body of the resistor off the circuit chassis and the use of short leads will minimize the stray capacitance and lead inductance.

Specify TI precision resistors!

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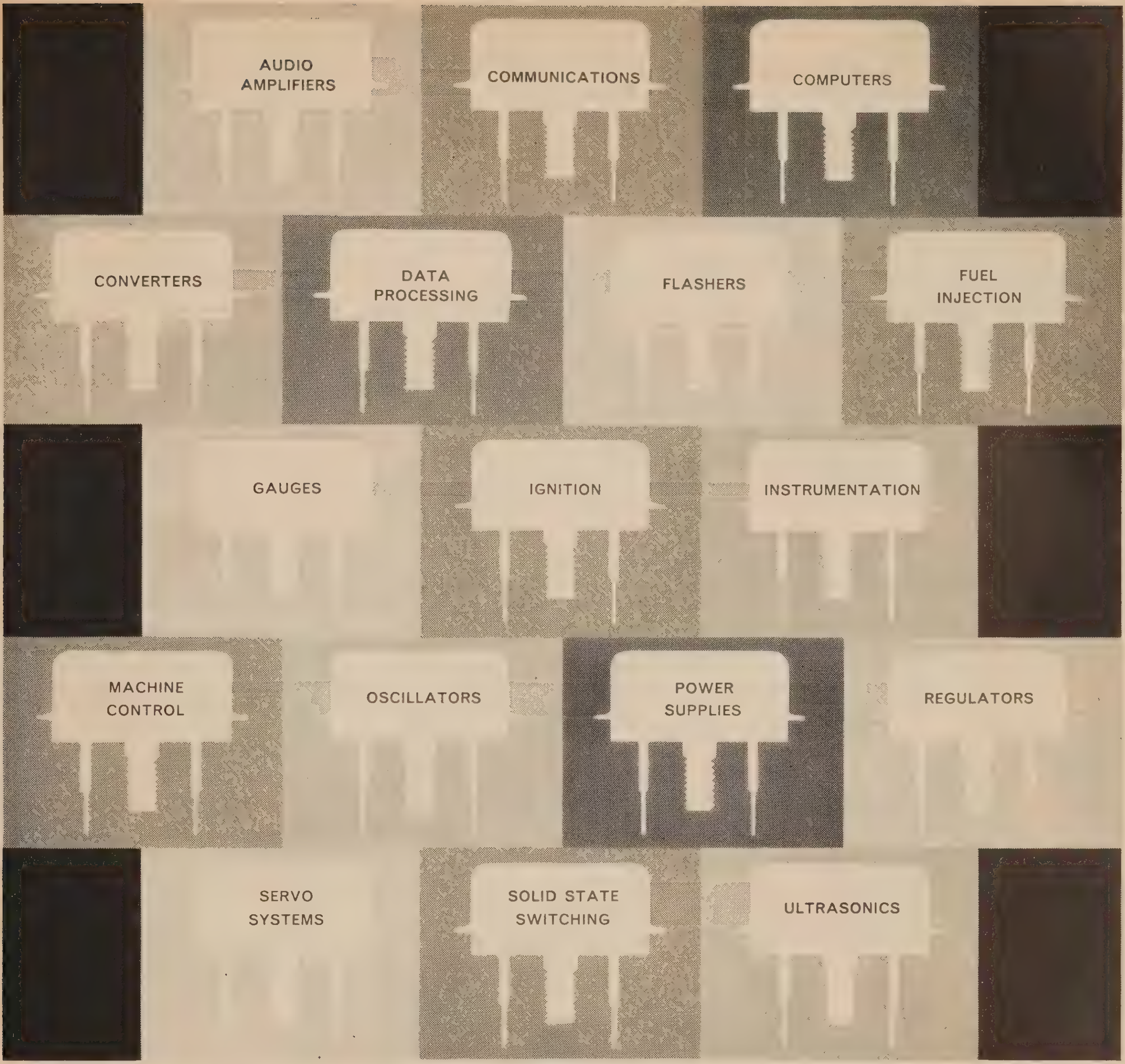
International Scientific Radio Union (URSI) Executive Committee, U. S. National Committee: Ernst Weber; Lloyd V. Berkner, alternate; L. G. Cumming, alternate
Joint IRE-EIA-SMPTE-NAB Committee for Inter-Society Coordination (JCIC) (Television): M. W. Baldwin, Jr.; W. J. Poch; William T. Wintringham; L. G. Cumming, alternate
National Stereophonic Radio Committee (NSRC): F. L. Hopper; L. J. Malmsten, alternate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■ This multi-purpose PNP germanium transistor is designed for general use with 28-volt power supplies, and for use with 12-volt power supplies where high reliability is desired despite the presence of voltage transients. ■ It has a high maximum emitter current of 15 amperes, a maximum collector diode rating of 80 volts and a thermal resistance below .8°C per watt. The maximum power dissipation at 71°C mounting base temperature is 30 watts. Low saturation resistance gives high efficiency in switching operations. ■ The 2N174 is versatile, rugged, reliable, stable and low priced. For more details or applications assistance on the 2N174 or other highly reliable Delco transistors, contact your nearest Delco Radio sales office.

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Santa Monica, California
726 Santa Monica Boulevard
Tel.: Exbrook 3-1465

Chicago, Illinois
5750 West 51st Street
Tel.: Portsmouth 7-3500

Detroit, Michigan
57 Harper Avenue
Tel.: Trinity 3-6560

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The KIN TEL Model 301 DC Voltage Standard and Null Voltmeter measures 1 to 501 volts, supplies 1 to 501 volts at up to 20 ma. Output is floating. Output voltage calibration is 0.02% or 2 mv. Long-term stability is 0.01%. Line and load regulation are 0.002%. Output hum and noise are less than 100 microvolts. Less than 0.01 ohm DC output impedance, and 0.2 millisecond response time. Available as rack or cabinet model. Price $795.

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Industrial Engineering Notes*

ASSOCIATION ACTIVITIES

The National Radio Stereophonic Committee has announced plans for a field test to help the Federal Communications Commission decide whether to authorize a stereo broadcast system. C. G. Lloyd, a former Chairman of the committee, told the 14th Broadcast Engineering Conference the tests probably would be conducted from station KDKA-FM in Pittsburgh and perhaps at other stations as well. Mr. Lloyd said plans call for use of a test tape with specially selected stereo material with the pickup recorded in at least two locations. One pickup would be made in an area with low signal strength, and one or both locations would be selected for ignition interference, multipath propagation and other problems.

Proponents of stereo who want their systems field tested, he said, should provide transmitting and receiving equipment and demonstrate that they can be set up readily for the tests.

ENGINEERING

A new subcommittee on Microminiature Electronic Components was recently organized by EIA to provide a mechanism for computer systems manufacturers to pass along component requirements to the component manufacturer for possible standardization. The group, chaired by Edward Keonjian (ARMA, Garden City, L. I., N. Y.), is concerned only with discrete components for the present, and has specifically excluded preassembled groups of components in modular form.

JAPANESE IMPORTS

The Business and Defense Services Administration at Commerce released figures showing that Japan exported electronic products to the United States worth $75.6 million last year—nearly three and one half times the value of those shipped here during 1958. The principal increase was accounted for by a sharp rise in the number of radio receivers exported, according to BDSA. Receivers worth $62.4 million were sent to the United States in 1959, compared with $17.9 million worth in 1958. The BDSA figures showed that the expansion in exports placed the Japanese electronic industries group among the top three earners of dollar exchange last year. The leading export to the U. S. was clothing valued at $111.7 million, followed by electronic products at $75.6 million, and iron and steel at $74.4 million. Japan's exports to the U. S. made up 56 per cent of its exports to all countries, which had a total value of $135.3 million. U.S.-bound exports during the first six months of 1959 totalled $22 million; during the third quarter, $24 million; and during the fourth quarter, $30 million.

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* The data on which these NOTES are based were selected by permission from *Weekly Reports*, issues of April 4, 11 and 18, published by the Electronic Industries Association whose helpfulness is gratefully acknowledged.

Section Meetings

AKRON

Student Papers—Joint meeting with Akron AIEE. 3/8/60.

ALAMOGORDO-HOLLOMAN

Election of officers. 3/21/60.

ALBUQUERQUE-LOS ALAMOS

Presentation of Student Papers. 3/28/60.

ATLANTA

"Radio Astronomy"; A. L. Bennett, Engrg. Experiment Sta. Georgia Tech. 2/26/60.

Report on IRE International and Region III Meeting, Speakers and Papers: C. Blakely, "Interference and Communication"; G. Smith, "Communications"; R. Pidgeon, "Components"; J. R. Walsh, "Subsystems & Microwave Tubes"; S. Witt, "Devices & Audio"; W. B. Jones, "Telemetry & Communications." 4/1/60.

BALTIMORE

Plant Tour of Western Electric Cable—Master of Ceremonies, Mr. Berquist, Western Electric Plant. 3/14/60.

BAY OF QUINTE

Tour of AMF Atomics. 3/16/60.

BENELUX

"High Power Microwave Tubes," O. Doehler, Compagnie General de T.S.F. Paris, France. 4/8/60.

BINGHAMTON

"The Vanishing Computers," C. F. King, Space Tech. Labs. 3/31/60.

CENTRAL FLORIDA

"Developments in Communication," Tom Combellick, Lenkurt Co. 3/17/60.

CENTRAL PENNSYLVANIA

"Trends in Solid State Circuit Design," Carl Volz, The Pennsylvania State Univ., University Park, Pa. 2/16/60.

"Future Methods of Power Generation," H. L. Smith, Westinghouse Elec. Corp., Pittsburgh, Pa. 3/15/60.

CINCINNATI

"The Model C Stellarator," C. L. Sonnenschein, C-Stellarator Associates, Princeton, N. J. 3/15/60.

COLUMBUS

"Hall Effect Devices & Their Uses," E. W. Bulman, Ohio Semiconductors, Inc., Columbus, Ohio. 3/31/60.

Inspection Trip of Industrial Nucleonics Corp. 4/5/60.

"Tunnel Diodes & Their Application," I. A. Lesk, Semi-Conductor Div. Gen. Elec. Corp., Syracuse, N. Y. 4/7/60.

"Silicon Solar Energy Converters," H. B. Prince, Semi-Conductor Div. Hoffman Electronics Corp., El Monte, Calif. 4/14/60.

CONNECTICUT

"Fundamentals of Semi-conductor Devices," Dr. Genser, Sperry Rand, South Norwalk. 2/17/60.

"The New Fast Transistors." J. E. Iwerson, Bell Telephone Labs., Murray Hill, N. J. 2/24/60.

"Transistor Performance Stabilization," S. K. Ghandi, Gen. Elec. 3/2/60.

"High Power Transistors & Their Applications," R. F. Morey, Clevite Transistor Products Co., Waltham, Mass. 3/9/60.

"PNPN Bistable Switching Devices," L. H. Dixon, Jr., Solid State Products, Inc. 3/16/60.

"Parametric & Tunnel Diodes," W. F. Chow, Gen. Elec. Co. 3/30/60.

(Continued on page 45A)

Electron Tube News ...from SYLVANIA

NOW AVAILABLE!

6AU4
GTA
SYLVANIA
MADE IN U.S.A.

FIRST TV DAMPER TUBE WITH SARONG CATHODE

...Sylvania-6AU4-GTA

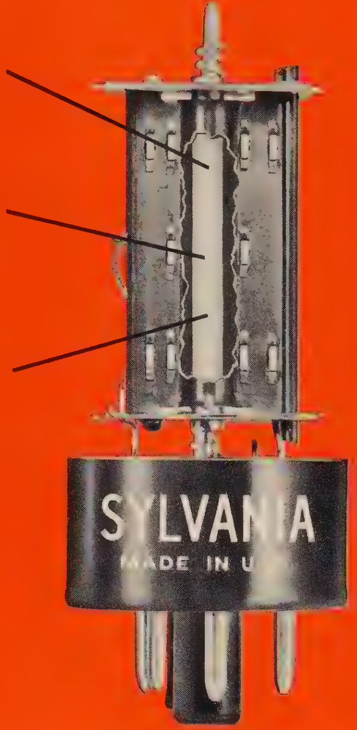
Sylvania has "beefed up" the heart of 6AU4-GTA — added life to its service, increased its stability and improved its over-all performance. 6AU4-GTA's bright future results directly from the use of the new concept in cathode coating for electron tubes—Sylvania *Sarong Cathode.*

An exclusive Sylvania development, *Sarong Cathode* is a thin film of cathode material made to precise measurements for uniformity and *wrapped* on an ultrasonically cleaned cathode sleeve. This provides greater control of density and smoothness of the cathode emissive material, greater control of the coating process, and provides high uniformity of electrical characteristics from tube to tube.

Sarong Cathode significantly minimizes plate-to-cathode arcing. Surface of **Sarong** is virtually free of "peaks and valleys," provides uniform spacing between cathode and plate.

Sarong Cathode eliminates "hot spots." Control of density of Sarong coating assures uniform temperature and emission over the entire cathode surface.

Sarong Cathode reduces heater-to-cathode arcing. Wrap-around cathode eliminates possibility of cathode emissive particles adhering to the inside of the cathode sleeve during the coating process.



SARONG ADDS LIFE TO TV DAMPER TUBE

Sylvania-6AU4-GTA illustrates the advantages attainable with the use of *Sarong Cathode.* It is the first TV damper tube to receive this specialized treatment. Other Sylvania types soon to utilize *Sarong* include 6AX4-GTA and 6DE4. This vital development plus several individual tube-type improvements combine to produce highly reliable TV damper tubes deserving of a place in your designs. Your Sylvania Sales Engineer will gladly give you complete technical data and delivery information. Ask him.

NEW!

TWO HIGH-VOLTAGE RECTIFIERS FOR TV PROVIDE "COOL" OPERATION, IMPROVED RELIABILITY

SYLVANIA
MADE IN U.S.A.
SYLVANIA
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ELECTRICAL CHARACTERISTICS	1N2	1AU3
Filament Voltage	1.25V ± 0.2V	1.25V ± 0.2V
Filament Current	200mA	200mA
Tube Drop for Ib = 7mA	100V	225V

RATINGS (Design Max. System)	1N2	1AU3
Inverse Plate Voltage		
Total DC and Peak	28,000V	30,000V
DC	24,000V	26,000V
Peak Plate Current	50mA	50mA
Average Plate Current	0.5mA	0.5mA

Sylvania-1N2 and -1AU3 feature improved structural design for greater reliability, longer life expectancy. Utilizing a large anode within a T-12 bulb, 1N2 and 1AU3 offer improved heat dissipation for "cool" operation and a reduced voltage gradient. Too, increased anode-to-filament spacing reduces electrostatic field forces that cause filament pulling and resultant plate-to-filament arcing.

Sylvania-1N2 has a tube drop of 100V @ 7mA Ib and a DC inverse plate voltage of 24KV. Sylvania-1AU3 has a tube drop of 225V @ 7mA Ib and a DC voltage of 26KV. Further, 1AU3 incorporates a helical shield as an additional safeguard against electrostatic charges. For complete technical data, see your Sylvania Sales Engineer.

For further information, contact the Sylvania Field Office nearest you. Or, write Electronic Tubes Division, Sylvania Electric Products Inc., 1740 Broadway, New York 19, N. Y.

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Section Meetings

(Continued from page 42A)

DALLAS

"Modern Traveling-Wave Tubes & Related Solid-State Microwave Amplifiers," C. L. Cuccia, Electron Tube Div., RCA, Harrison, N. J. 3/10/60.

"Check Sorting Equipment," Gordon Perry, R. L. Wolfork, National Data Processing, Dallas, Texas. "Thyroid Scanner," John Drew, Texas Electronics Products, Dallas, Texas. 3/15/60.

DENVER

"Future Research & Development in the Electrical Industry is Necessary," Miles Maxwell, Westinghouse Electric Corp., East Pittsburgh, Pa. 2/12/60.

"Application of Magnetic Materials at Radio & Microwave Frequencies," R. D. Harrington, Boulder Labs., Nat'l. Bureau of Standards, Boulder, Colo. 3/17/60.

DETROIT

"A Stereophonic System for AM Stations," L. R. Kahn, Kahn Research Labs. 3/18/60.

ELMIRA-CORNING

"Infra-red Detectors," Henry Levinstein, Syracuse Univ., Syracuse, N. Y. 3/8/60.

EL PASO

"Water Rights," G. M. Dixon, Texas State Board of Water Engineers. 2/25/60.

EMPORIUM

Film—"Effect of the Ionosphere on Radiowave Propagation,"—Film—"Principles of Gas Filled Tubes." 2/16/60.

EVANSVILLE-OWENSBORO

Tour of Green River Steel mill. 3/16/60.

FLORIDA WEST COAST

"Radio Frequency Interference," D. R. J. White, Frederick Research Corp., Wheaton, Md. 3/16/60.

FORT HUACHUCA

"Basic Concepts of Single Sideband," R. Bettin, Stromberg-Carlson Co. 3/28/60.

FORT WAYNE

Christmas Ball. 12/4/59

"The Civil Air Patrol Interference Mystery," John Richards, Magnavox Co., Fort Wayne, Ind. 1/7/60.

"The Volscan Air Traffic Control Systems," D. E. Wolfe, Crosley Div., AVCO Mfg. Corp., Cincinnati, Ohio. 2/4/60.

"Communications Systems for Project Mercury Space Capsule," William Benner, McDonnell Aircraft Corp., St. Louis, Mo. 3/3/60.

FORT WORTH

"Recent Advances in Parametric Amplification," L. A. Blackwell, Texas Instruments, Dallas, Texas. 3/15/60.

GAINESVILLE

"Basic Principles of Inertial Guidance," J. Hobbs, Sperry Gyroscope Co., Great Neck, N. Y. 3/9/60.

"Microwave Ferrite Devices," B. J. Duncan, Sperry Microwave Electronics Co., Clearwater, Fla. 4/13/60.

HAMILTON

"Selenium & Silicon Rectifiers," A. Dean, Syntron Canada Ltd., Stoney Creek, Ont. 3/14/60.

HAWAII

"Control & Safety Features of a Submarine Nuclear Reactor," Wallace Y. F. Chang, U. S. Navy, Pearl Harbor Naval Shipyard, Hawaii. 2/10/60.

"Hawaiian Telephone Company's Microwave System Provides Trunding for Kona," E. C. Schoen Hawaiian Telephone Co., Honolulu, Hawaii. 3/9/60.

HUNTSVILLE

"Microwave Networks," R. E. Lee, Texas Instruments. 3/31/60.

INDIANAPOLIS

"Scattering of Electromagnetic Waves," I. H. Gerks, Collins Radio Co., Cedar Rapids, Iowa. 3/30/60.

ITALY

Organizational Meeting. 3/4/60.

ITHACA

"Recent High-Frequency Solid-State Developments," W. E. Kock, Research Labs. of Bendix Aviation, Detroit, Mich. 3/10/60.

KANSAS CITY

"Development of Microwave Impedance Standards & Measurement Techniques at the National Bureau of Standards," W. J. Anson, National Bureau of Standards, Boulder, Colo. 2/9/60.

"Humanities in Life & Education of the Engineer & Scientist," John Burchard, Mass. Inst. of Technology. 3/23/60.

Student Paper Competition: "Doppler Radar," Donald White, Central Tech. Inst., "Computer Design of Transistor Cascades," Dale Cole, Univ. of Kansas; "Bass Reflex Enclosures," James Hall, Kansas State Univ. 4/12/60.

LITTLE ROCK

Tour of International Facilities at Pine Bluff, Mr. Brodnax, International Paper Co., Pine Bluff, Ark. 3/19/60.

"Use of Microwave for Telephone Communications," H. H. Davenport, Southwestern Bell Telephone Co. 4/18/60.

LONG ISLAND

"Fundamental Considerations," W. W. Mumford, Bell Telephone Labs, Whippany, N. J. 1/28/60.

"Low Noise Antennas," R. W. DeGrasse, Bell Telephone Labs., Murray Hill, N. J. 2/4/60.

"FAA Air Traffic Control Height-Finding Radars," K. F. Bierach, Jr., Federal Aviation Agency. 2/9/60.

"Low Noise Amplifiers," Seymour Okwit, Airborne Instruments Labs., Melville, N. Y. 2/11/60.

"Techniques of Signal Recovery from Noise," W. M. Siebert, MIT, Cambridge, Mass. 2/18/60.

"A Practical Low Noise System," F. G. Haneman, Airborne Instruments Lab., Melville, N. Y. 2/25/60.

Fellow Awards Cocktail Party. 3/20/60.

LOS ANGELES

"Business Aspects of Engineering in the Space Age," R. C. Fuller, Bendix-Pacific, a Div. of Bendix Aviation. 3/1/60.

LUBBOCK

"Microwave Equipment," R. S. Houston, Collins Radio, Richardson, Texas. 3/22/60.

MIAMI

Engineers Exposition. 2/25/60.

"Automatic Distribution Control System," William Nola, Fla. Power & Light Co. 3/4/60.

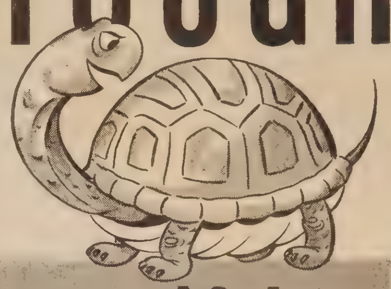
MILWAUKEE

"The Automobile of the Future," D. N. Frey, Ford Motor Co., Detroit, Mich. 2/24/60.

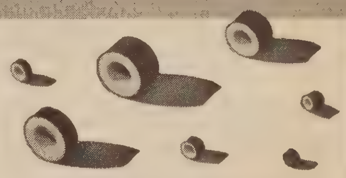
"Communications and Control in a Visual System," R. W. Jones, Northwestern Univ., Evanston, Ill. 3/15/60.

(Continued on page 46A)

TOUGH



...AS A TURTLE'S BACK



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200cps-25mc

FAST!

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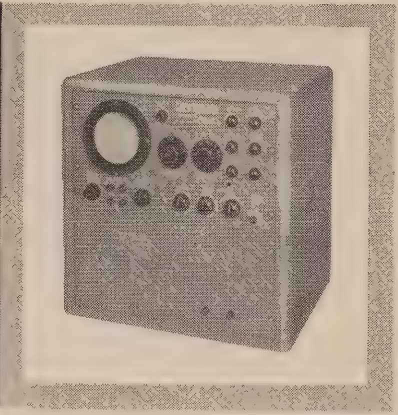
PANORAMIC's economical SPA-3/25 SPECTRUM ANALYZER



Widely used for high-speed location, identification and analysis of random and discrete signals, the SPA-3/25 automatically separates and measures the frequency and amplitude of signals in spectrum segments up to 3mc wide, selectable anywhere between 200 cps and 25mc. Direct readouts of frequency distributions and amplitudes of signals are provided respectively on calibrated X and Y axes of a 5" long-persistence CRT. The SPA-3/25 samples the spectrum at a 1-60 cps rate.

Panoramic presentation of the Model SPA-3/25

1. permits quick location of signals, minimizes chances of missing weak signals or holes in the spectrum
2. speeds up measurements by eliminating tedious point-by-point plots
3. enables fast, reliable detection of comparatively low level discrete signals present in random spectra through use of adjustable narrow IF bandwidths and correlation techniques
4. allows identification and subsequent analysis of dynamic characteristics of modulated signals and noise.

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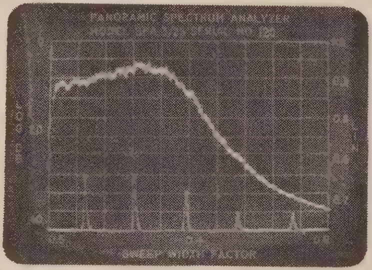

Noise spectrum analysis using internal video smoothing filter presents noise envelope average versus frequency in readily appreciated form. Internal marker pips are 500kc apart.

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Frequency Range: 200cps-25mc in 2 bands
Sweepwidth: Variable, calibrated from 0 to 3mc
Center frequency: Variable, calibrated from 0 to 23.5mc
Markers: crystal controlled, 500kc and harmonics to 25mc
Resolution: Variable, 200 cps to 30 kc
Sweep rate: Variable, 1 cps to 60 cps
Amplitude Scales: 20 db linear, 40 db log, 10 db square law (power)
High sensitivity: 20 μv full scale deflection
Attenuator: 100 db calibrated
Response Flatness: ±10% or ±1 db
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Section Meetings

(Continued from page 45A)

MONTREAL

"Transistors & Other Semiconductor Devices," R. Fortier, Bell Telephone Co. of Canada, Montreal, 3/17/60.

NEW ORLEANS

"IRE Outlook from the National Level," R. L. McFarlan, IRE, President. 2/9/60.

"Analog-to-Digital Conversion Techniques," K. A. Bacon, Norden, Div. United Aircraft Corp. 3/3/60.

"Your IRE," C. E. Harp, School of Engrg., Univ. of Oklahoma, Norman, Okla. 3/5/60.

NORTH CAROLINA

"UHF & Microwave Antenna Design," L. P. Tuttle, Jr., Melpar Corp., Falls Church, Va. 3/11/60.

"Microwave Transmission Techniques," T. E. Mardis, Bell Telephone Labs, Inc., Winston-Salem, N. C. 4/15/60.

NORTHERN ALBERTA

"Digital Computers for Small Businesses," P. Dernick, University of Alberta, Edmonton. 3/8/60.

NORTHERN NEW JERSEY

"Solid State Electronics 1960–1964," J. B. Angell, Philco Corp. 2/10/60.

"Reminiscences of Electronics Growing Pains," Frank Stanton. 3/9/60.

OKLAHOMA CITY

"Parametric Amplifiers & the Diode Capacitors Employed," K. E. Mortenson, General Elec. Research Lab., Schenectady, N. Y. 3/8/60.

OMAHA-LINCOLN

"The Day the World Tumbled," C. P. Thomas, Hughes Aircraft, Los Angeles, Calif. 3/18/60.

Annual Business Meeting & Panel Discussion, C. L. Doll, Corps of Engineers, Omaha, Neb. 4/5/60.

ORLANDO

"The Project System vs The Technical Section," A. R. Gray, The Martin Co., Orlando, Fla. 3/16/60.

PHILADELPHIA

"New Uses for Old Radio Frequencies," J. A. Pierce, Div. of Applied Science, Harvard Univ. 3/2/60.

PHOENIX

"Physiological Problems of Space Travel," James Gaume, Glenn L. Martin Co., Denver, Colo. 2/16/60.

"Theory & Application of Ferromagnetic Resonance," C. L. Hogan, Motorola Semiconductor Div., Phoenix, Ariz. 3/8/60.

PORTLAND

Panel Discussion—"Attitudes & Challenges Facing the Engineer in His Field in Development & Management," Howard Vollum, James Kirwan, Kenneth Trolan. 2/20/60.

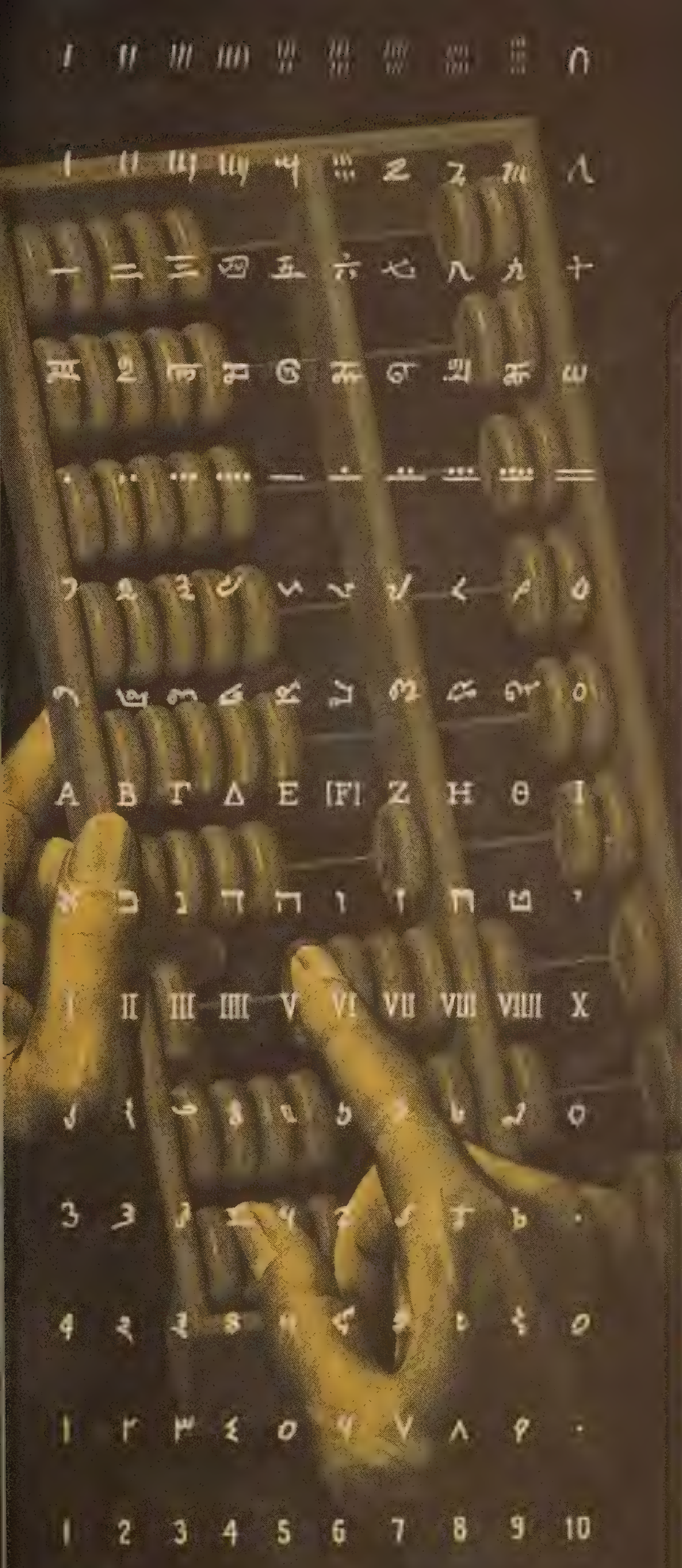
"Contributions in the Field of Impedance Measurements," Armen Grossenbacher, Electro-Scientific Instruments, Portland, Ore. 3/17/60.

QUEBEC

"Advantages of S.S.B. over Amplitude Modulation," D. V. Carroll, TOC (Canada) Ltd., Ottawa, Ont. 2/22/60.

"Unusual Facets of Utilities," J. A. Smith, Shawinigan Water & Power Co., Shawinigan, P. Q. 3/8/60.

(Continued on page 48A)



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For nearly 2,000 years man's only computing machine was the Abacus. In varying forms, it was used by the ancient Egyptians, Greeks, Romans and Chinese.

LFE, long in the foreground of computer research and development, has improved upon the whole family of mathematical computers. For instance, now in production for the Air Force is an operational-digital computer that combines the convenience of real time computation with the inherent accuracy of digital data handling.

LFE is experienced in the design and manufacture of Computer Systems for both military and industrial applications.

Further details about LFE Computer Systems may be had by writing the Vice President of Marketing. Ask for Technical Data Digest No. 6045.

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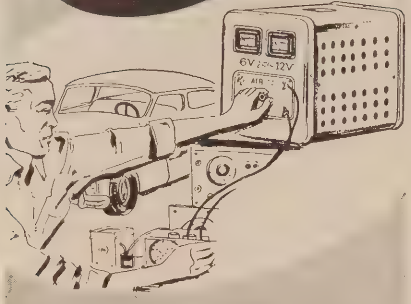

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Section Meetings

(Continued from page 46A)

SAN ANTONIO-AUSTIN

Joint Social Meeting. 9/24/59.

"Man in Space," Hubertus Strughold, Aviation Medicine, San Antonio, Texas. 11/19/59.

SCHENECTADY

"The Dew Line," Howard Davenport, New York Telephone Co. 3/8/60.

SHREVEPORT

"MIT Radar," Kellum Young, Louisiana Tech., "Esaki Diode," Carl Townsend, Louisiana Tech. 3/8/60.

SYRACUSE

"How Much Space," J. E. Keister, General Electric Co., Electronics Park Syracuse, N. Y. 4/8/60.

TOLEDO

"Electronics in Medicine," W. H. Hartung, H. J. DeVaunt, St. Charles Hospital. 3/10/60.

TORONTO

Panel Discussion, J. S. Ford, Canadian National Telegraphs. 3/16/60.

"Thermal-Electric Energy Conversion," G. M. Graham, Univ. of Toronto. 3/28/60.

TUCSON

"Considerations of Tropospheric Scatter Systems for Tactical Field Use," J. C. Dominque, US Army Electronic Proving Ground, Ft. Huachuca, Ariz. 3/22/60.

VANCOUVER

"Switching Considerations for Standby Application in Microwave Installations," Ralph Marsh, Lenkurt Electric Co. (Canada Ltd.) Vancouver, B. C. 10/19/59.

"BCB/TV Network Programme Delay Centre," G.E. Waters, CBC, Plant Dept., Montreal, P. Q. 11/16/59.

"Some Outstanding Problems in Microwave Research," G. B. Walker, Electrical Engrg. Dept., Univ. of B. C. 12/21/59.

Annual Students Night—"Parametric Amplifiers," Donald McDairmid; "Semiconductor Image Intensifiers," Keith Plant; "Magnetic Recording," Edward Taillefer. 2/15/60.

VIRGINIA

"Patents & Engineers," J. O. Tresansky, Langley Research Center, Hampton, Va. 3/11/60.

WASHINGTON

"How to Capture a Technical Audience," D. C, Daniel, Lawyer; Otis Gregg, Technifax Corp. 3/17/60.

WILLIAMSPORT

"Thermoelectricity," Robert Artman, Bucknell Univ., Lewisburg, Pa. 3/16/60.

WINNIPEG

"Regulation of Insect Habits by Natural Signals," A. J. Thorsteinson, Univ. of Manitoba. 3/2/60.

Annual Dinner Meeting—R. A. Johnson, Univ. of Manitoba. 4/1/60.

SUBSECTIONS

BUENAVENTURA

"Tunnel Diodes," Clarence Carter, Space Technology Lab., Los Angeles. 3/9/60.

EAST BAY

"Development & Use of Magnetic Recording for Color TV," Joseph Roizen, Ampex Corp., Redwood City, Calif. 3/14/60.

EASTERN NORTH CAROLINA

"UHF & Microwave Antenna Design," L. P. Tuttle, Jr., Melpar Corp., Falls Church, Va. 3/11/60.

Tour of Computation Center, Univ. of North Carolina, Ruth Kurtzwil, Lynn Caviness, Charles Bartee, Computation Center, Univ. of No. Carolina. 4/8/60.

LANCASTER

"The Universal Checkout & Detection of Guided Missiles," M. R. Beck, Bendix Aviation Corp., York, Pa. 2/24/60.

MEMPHIS

Demonstration of Teaching Procedures in A.T.B. School—N.A.T.T. C. 3/11/60.

NEW HAMPSHIRE

"Infra-Red," E. W. Bivans, Infra-Red Industries, Waltham, Mass. 3/16/60.

NORTHERN VERMONT

"Youth in Industry," R. J. Lyman, New England Elec. Service. Boston, Mass. 3/31/60.

PANAMA CITY

"The Engineer, His Education, and His Place in Society," B. J. Dasher, School of Elec. Engrg., Georgia Tech, Atlanta, Ga. 3/15/60.

"Space Communications," L. F. Gray, Transmission Lab., ITT Labs., Nutley, N. J. 4/12/60.

PASADENA

"Space & National War Strategy," R. C. Mack, Hughes Aircraft, Culver City, Calif. 2/18/60.

"Earth Movements," Hugo Benioff, Calif. Inst. of Technology, Pasadena, Calif. 3/15/60.

READING

"Technical Discussion of Four Problems," W. I. Huyett, The Polymer Corp., Reading, Pa. 1/20/60.

"Is the Universe Planned?," W. G. F. Swann, The Franklin Inst., Phila., Pa. 2/24/60.

"What Makes Materials," J. N. Hobstetter, Univ. of Pennsylvania, Phila., Pa. 3/17/60.

SANTA ANA

"Extra-Sensory Perception," J. Banks Rhine, Duke Univ., Durham, N. Carolina. 3/9/60.

SANTA BARBARA

Presentation of Slate for Candidates. 3/16/60.

WESTERN NORTH CAROLINA

"Experimental Electronic Telephone Systems," B. J. Yokelson, Bell Telephone Labs., Whippany, N. J. 3/24/60.

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with both GAS DISCHARGE and FERRITE DUPLEXERS

Selecting a duplexer for high-power applications involves consideration of peak power, average power, transmit loss, receive loss, expected life, and versatility of operation.

All Microwave Associates high power gas duplexers utilize special window structures for optimum switching efficiency without sacrifice in low-level loss characteristics. These windows insure reliable, long-life performance. Both our gas and ferrite duplexers may be operated over very broad bandwidths at the common microwave frequencies.

Exceptionally complete ultra-high-power design and test equipment is utilized by our Research and Production Departments. Each duplexer is fully tested at maximum rated power before shipment.

We have extensive experience in designing and manufacturing high-power duplexer devices and are interested in working on newest ultra-high-power applications. We are now developing ultra-high-power duplexers for more efficient switching at UHF, L, C, and S bands.

Our Applications Engineers would like to discuss the future of high power duplexing with you.

Frequency Band	Duplexer Type	Peak Power	Average Power	Transmit Loss (max.)	*Receive Loss (max.)	Bandwidth
UHF	Gas	5 Mw	300 Kw	0.1 db	0.4 db	Tunable
	Gas	25 Mw	75 Kw	0.1 db	0.4 db	10% Nominal
L	Gas	25 Mw	50 Kw	0.1 db	0.5 db	
S	Gas	6 Mw	30 Kw	0.1 db	0.7 db	
	Ferrite	3 Mw	5 Kw	0.5 db	0.9 db	
C	Gas	5 Mw	5 Kw	0.1 db	0.7 db	
	Ferrite	5 Mw	7.5 Kw	0.3 db	0.8 db	
X	Gas	500 Kw	500 W	0.2 db	1.0 db	
	Ferrite	1 Mw	1 Kw	0.3 db	0.9 db	
Ku	Gas	150 Kw	150 W	0.2 db	1.0 db	
	Ferrite	150 Kw	150 W	0.3 db	0.9 db	
Ka	Ferrite	75 Kw	75 W	0.3 db	1.1 db	4% Nominal

All Microwave Associates duplexers incorporate low-loss, long-life, receiver protectors which guarantee crystal protection over wide temperature ranges and under extreme environmental conditions.

*The duplexer receiver loss includes the loss due to receiver protector TR tubes.

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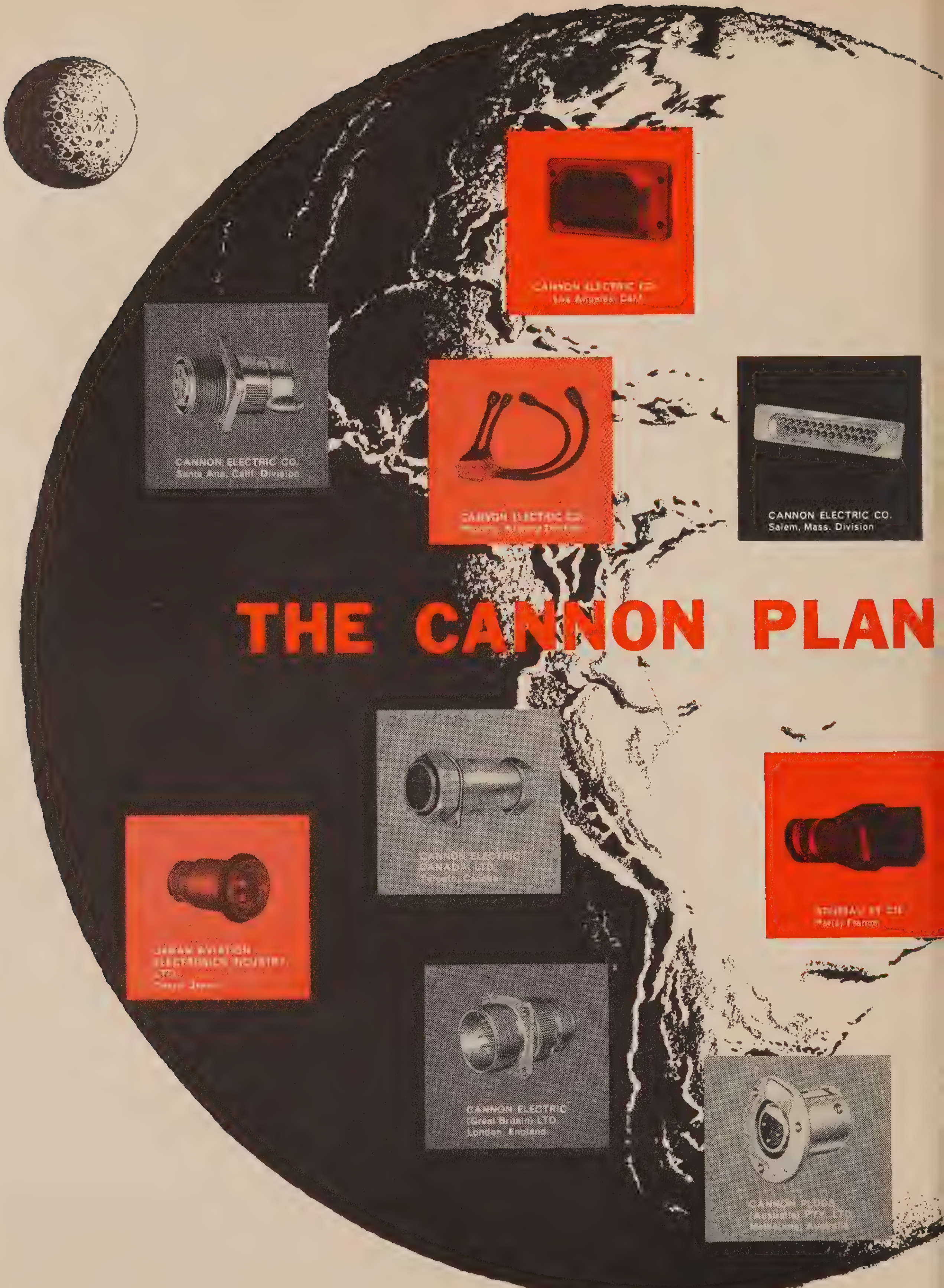
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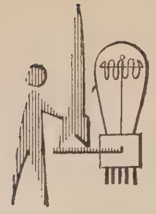
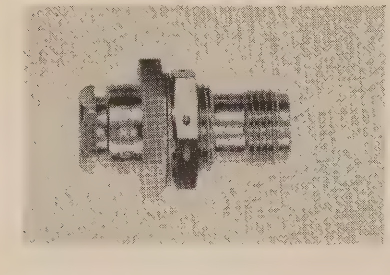
CANNON ELECTRIC COMPANY, 3208 Humboldt St., Los Angeles 31, Calif.



NEWS New Products

Coaxial Connectors

Coaxial connectors plotted to enable users to select units which meet the desired VSWR in critical applications can now be furnished by **Kings Electronics Co., Inc.,** 40 Marbledale Rd., Tuckahoe, N. Y.



A calibration curve is supplied with each connector which can be tested and plotted at every 100 mc point over the entire range if so desired. Both KA 11-06 and KA 51-05 coaxial connectors are part of the TNC group and are available for specific or broad band use. They are manufactured to meet government specifications.

Data on the TNC group of connectors can be secured by writing to the firm.

Differentially Pumped High Vacuum Headers

Physical Sciences Corp., (formerly Technical Industries Corp.), an affiliate of Packard-Bell Electronics, 380 North Fair Oaks Ave., Pasadena, Calif., offers differentially pumped high vacuum headers, Part No. C7-179-341. These are available in three high temperature (to 1000°F), high vacuum assemblies. These headers are complete with high temperature cables, and are ready for heliarc welding to the user's instruments. The performance of these units has been proven in actual use under the most severe environments encountered in high temperature nuclear reactor studies.

Specifications are: Vacuum Leak Rate, 1×10^{-14} cc/Helium/second; Insulation Resistance, 2×10^9 ohms. (Higher leakage resistance available as a premium feature to a maximum of 2×10^{12} ohms); Operating Temperature Range, -350°F to $+1000$°F, Voltage Rating; 1500 volts; Cross Section Capture of Seals; Less than eighteen (18) Barns, Material: 304 Stainless Steel—Inconel and Durock Seals; Pin Configurations; 12 pin, 18 pin, 26 pin; Cable Configurations; 6 cable, 8 cable, 10 cable.

For additional information, write to the firm.

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

Standing Wave Amplifier

The new portable PRD 277-B Standing Wave Amplifier, manufactured by **Polytechnic Research & Development Co., Inc.,** 202 Tillary St., Brooklyn 1, N. Y., features low inherent noise (0.007 μv) and attenuation in 5 db steps. The Model 277-B provides an attenuation range of 85 db; plus one regular and four expanded VSWR scales; meter scales automatically normalized; and a $5\frac{3}{4}$ inch meter with 1% linearity.

Weak signals which once were undetected by conventional instruments can now be measured with the PRD 277-B due to its low inherent noise level.

Additional specifications of the 277-B are: front panel adjustments of gain (15 db range) and bandwidth (4 to 40 cps); front panel meter monitors bias control and center frequency (1000 cps) of the amplifier is adjustable over a 2% range.

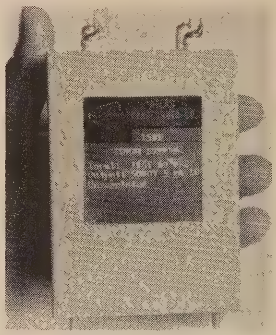
The unit is $7\frac{3}{4}''$ wide, $10\frac{1}{2}''$ high, 11" deep and weighs 14 lbs.

For further information contact the firm.

Power Supply

Now in production from **Atlas Transformer Co.,** 1839 Moore St., San Diego 1, Calif., is the Model 1501, a 5000 volt direct current power supply in a small package ($2\frac{5}{16} \times 3 \times 4\frac{1}{4}$ inc.). This unit is capable of delivering up to 5 ma. Model 1501 has less than 1% ripple and is designed for a 115-volt ac 60 cps input.

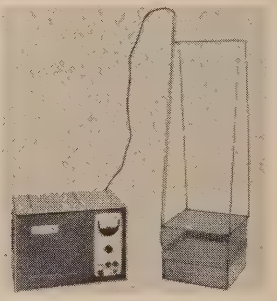
Also available are dc power supplies at 1100-volt and 15,000-volt outputs rated at 5 ma each, packaged with optimum space factor in mind.



Transducers Sealed In Cleaning Basket

The Circo Ultrasonic Corp., 51 Terminal Ave., Clark, N. J., announces the development of a solid, stainless steel Circosonic basket with barium titanate transducers sealed in the bottom. Connected to the Circosonic generator, Model PG125, the Model CB125 basket can be submerged in virtually all solutions for use as an ultrasonic cleaner.

The basket has an operating frequency of 40 kc and can use either the regular 180° barium titanate transducers or the high temperature 300° barium titanate transducers.



It may be used in the warm liquid rinse of a standard liquid-liquid vapor degreaser; in hot or cold solution tanks; or in the precleaning tanks of a plating system.

The Model CB125 basket (as illustrated) has overall dimensions of $9\frac{1}{2}''$ long by $9\frac{1}{2}''$ wide by 33" high. It weighs $16\frac{1}{2}$ pounds. Other standard sizes available.

The Model PG125 generator (as illustrated) has overall dimensions of 14" wide by 10" high by $10\frac{1}{4}''$ deep. Output is 125 watts average, 250 watts peak; power output is 500 watts, 115 volts, 60 cps 1 ph; it has a 6 foot coaxial cable connection and weighs 30 pounds overall.

For further information on these and other models, write to the firm.

(Continued on page 112A)

Creative Microwave Technology

Published by MICROWAVE AND POWER TUBE DIVISION, RAYTHEON COMPANY, WALTHAM 54, MASS., Vol. 2. No. 4

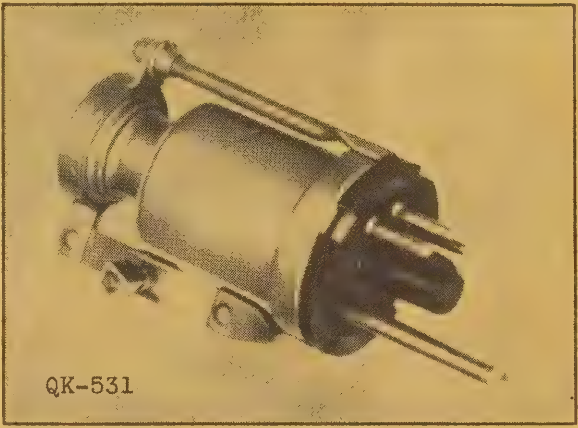
RAYTHEON KLYSTRON CLOCKS 62,000 HOURS OF SERVICE

--tube retired after seven years of continuous operation

We don't send out 62,000-hour warranties; however, you can expect unusual performance from Raytheon klystrons. Take the tube cited above -- the QK-531 -- a 6,575-6,875 mc reflex klystron which we conservatively warrant for 7,500 hours. As the local oscillator in the Houstonia, Missouri, link of the Panhandle Eastern Pipeline Company's 400-mile microwave system, the tube performed a major function in relaying up to ten channels of information between the Odessa and Boonville stations.

How is this kind of performance built into a tube? Advanced manufacturing techniques and rigorous quality control is the answer.

If you need low-power coverage of government, studio link and common carrier frequency bands, look into the characteristics of Raytheon's complete line of klystrons.



The QK-531 is particularly suited for local oscillator service in microwave receivers. It is useful, also, as a local oscillator in microwave spectrum analyzers, as a pulse generator for testing circuit response and as a frequency modulated source in microwave relay links.

Homer Marrs of Motorola presents gold-plated klystron trophy to F. J. McElhatton, Panhandle Eastern Pipeline Co. J. A. Fowler, Supervisor of Communications for Panhandle, is at the left. Prized klystron, the Raytheon QK-531, performed for 62,000 hours.

Close control of product quality and costs at every state of production is responsible, in part, for Raytheon's success in meeting industry and government specifications. Every step of assembly is spot checked by inspectors, each with 10 years or more experience in microwave tube production.

Excellence in Electronics

You can obtain detailed application information and special development services by contacting: Microwave and Power Tube Division, Raytheon Company, Waltham 54, Massachusetts. In Canada: E. Waterloo, Ontario.

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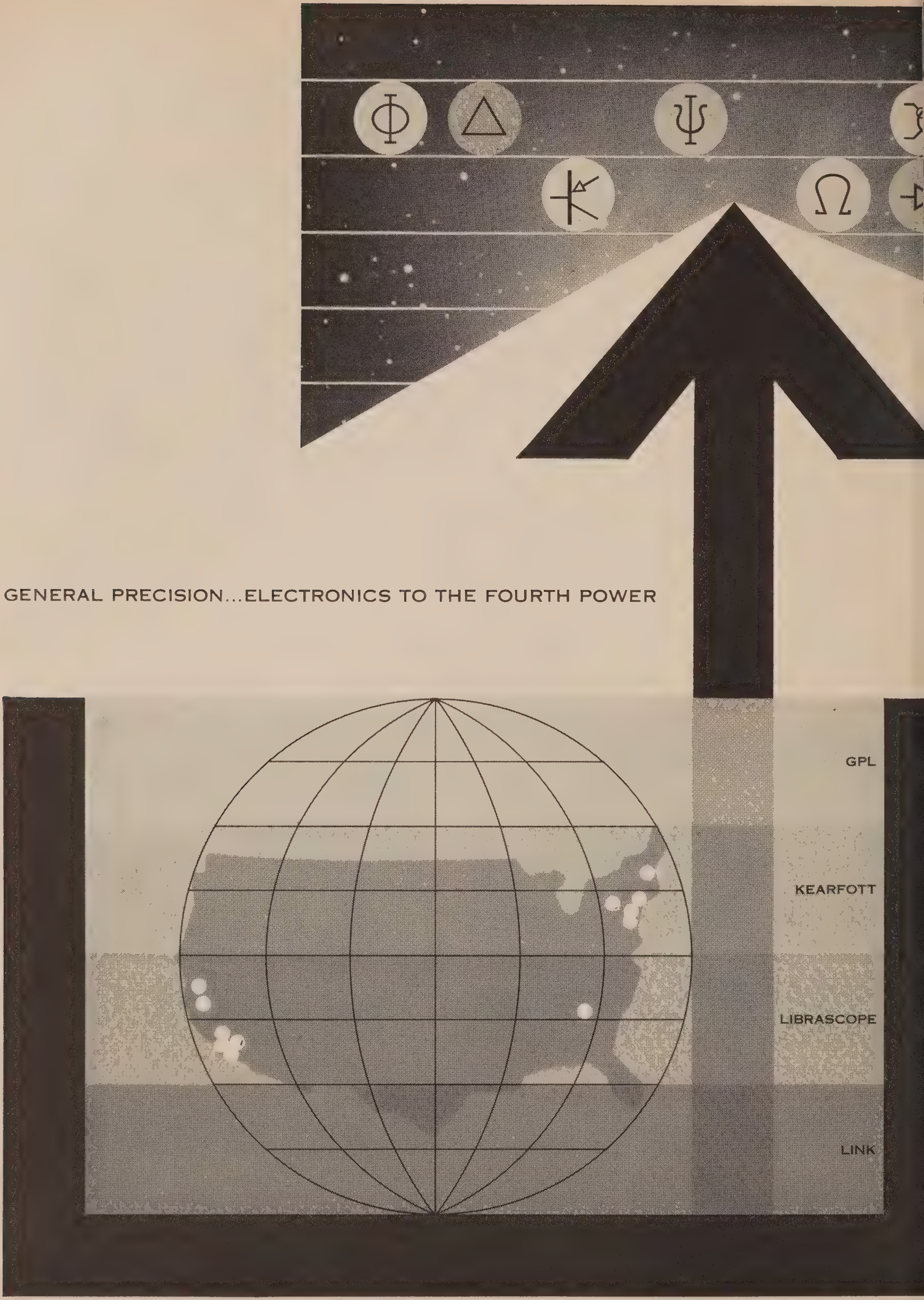
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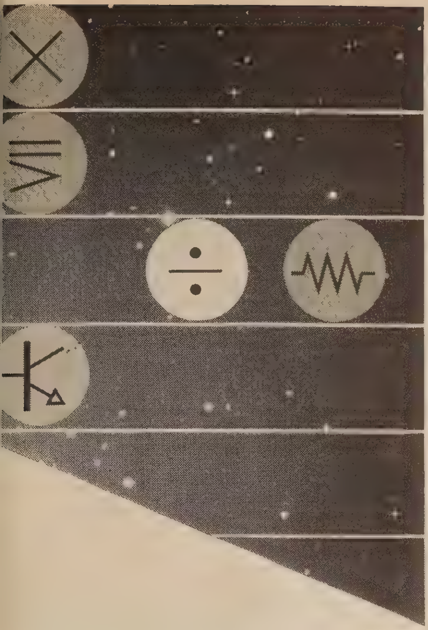

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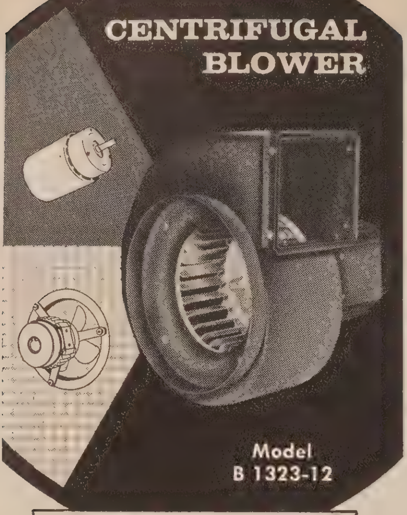

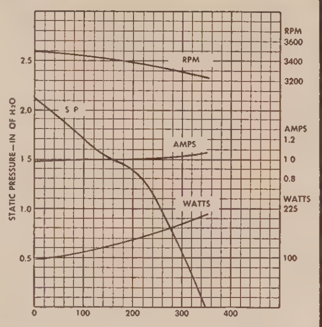

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Ambient: 85°C
Lubrication: Reservoirs assure continuous lubrication of bearings.
Units constructed and tested to applicable military specifications.

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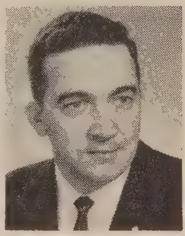
WRITE TODAY FOR OUR NEW CATALOG

IRE People

Dr. Robert M. Page (SM'45–F'47), the man who built the first pulse radar system in the United States, has been given the President's Award For Distinguished Federal Civilian Service. He has served as the Director of Research at the Naval Research Laboratory since November, 1957. In this capacity, he directs and coordinates the Laboratory's overall research program, which includes research in 13 fields of the physical sciences.


R. M. Page

A native of St. Paul, Minn., he came to the Laboratory in 1927 as a junior physicist, shortly after receiving the B.S. degree from Hamline University, St. Paul. His earlier research was in the field of frequency standardization and measurement; by 1934, he had eight patents in the field of electronics. That same year, he built the first pulse radar system, and with it detected aircraft in flight. After further research, he developed the theory of radar receiver design and, with a small group assigned to him, led the invention and development of the circuits and components necessary to the military use of pulse radar, thus hastening the development of radar in this country.

During his more than 30 years of service, he has pursued development of the finer aspects of the art of radar. More than 40 patents have been issued to him and 27 are pending.

In addition to the B.S. degree, he has the M.A. degree in Physics from George Washington University, Washington, D.C., and D.Sc. (honorary) from Hamline University. In honor of his contributions to the development of radar, the Electronics Laboratory of Hamline University was named the Robert M. Page Electronics Laboratory in 1952.

On March 8, 1960, President Eisenhower presented to Dr. Page the President's Award for Distinguished Federal Civilian Service—the highest honor bestowed on career civil service employees. He was honored for "remarkable achievements in the field of electronics research, most particularly in the original development of radar."

Dr. Page has also been awarded the Certificate of Award from the Office of Scientific Research and Development; the Distinguished Civilian Service Award; the Presidential Certificate of Merit; the Harry Diamond Memorial Award of the IRE; the Stuart Ballantine Medal of the Franklin Institute, and the 1959 Captain Robert Dexter Conrad Award.

Dr. Page is a fellow of the American Association for the Advancement of Science and American Scientific Affiliation and a member of the Acoustical Society of America, American Geophysical Union NRL Branch of Scientific Research Society of America and the American Institute of Physics.

Use Your
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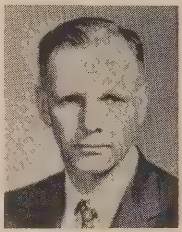
It's Valuable

⁂

Robert W. Pearson (M'50), formerly director of manufacturing for American Machine & Foundry Company's Government Products Group, has been appointed to the newly-created staff position of director of production for the company, it was announced by Carter L. Burgess, AMF president.


R. W. Pearson

Mr. Pearson joined AMF as deputy general manager of the former Electronics Division in Boston in 1956 and was made director of manufacturing for the Government Products Group in 1958.

Before joining AMF he was with RCA at Camden, N. J. as senior staff engineer in the production department, and later was administrator of mechanical design and manager, engineering standards and services. He was subsequently named manager of product planning.

Prior to that he was superintendent of the Radio division of Federal Television and Radio Corporation from 1946 to 1948. From 1937 to 1942 he was an industrial electronic control engineer with Westinghouse Electric Company, Pittsburgh, Pa.

During World War II, he served as research and development officer and as a contracting officer with the U. S. Army Signal Corps in Washington, D.C. and Fort Monmouth, N. J., with the rank of Lieutenant Colonel.

He was graduated from Drexel Institute with the B.S. degree in Electrical Engineering in 1935. He earned the M.S. degree in Electrical Engineering in 1941 at the University of Pittsburgh.

Mr. Pearson is a member of the American Mathematical Society. He holds a Reserve commission as Colonel in the Signal Corps.

⁂

Dr. Morton B. Prince (SM'55), a pioneer in the semiconductor field, has been appointed vice president and general manager of the Semiconductor Division of Hoffman Electronics Corporation.

He succeeds **Maurice E. Paradise** (SM'53), who has been named to the new

(Continued on page 58A)

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Two Cycle Pen Response	
D-c Milliampere Ranges	¼ ma to 100 ma
A-c Ampere Ranges	0.25 A to 25 A
D-c Ampere Range	100 mv for use with standard shunts
Expanded Scale A-c Voltage Ranges	80-130 V, 160-260 V, 320-520 V
A-c and D-c Voltage Ranges	10 V to 1000 V
Frequency Ranges	50, 60, 400 cps
Five Cycle Pen Response	
D-c Milliampere Range	5 ma

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It's a "thinga-ma-jig that ......"

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(5) Product code numbers reduce complex and duplicate listings, saving you "searching" time and effort.

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THE INSTITUTE OF RADIO ENGINEERS
1 East 79th Street, New York 21, N.Y.

(Continued from page 56A)

position of corporate vice president in charge of product planning.

Mr. Paradise's immediate assignment will be to "strengthen and expand the proprietary product position of the company," said H. Leslie Hoffman, president.

"He will work with management and the engineering and marketing activities in each division to accelerate the introduction of new products."

Dr. Prince has more than a decade of experience in solid state electronics and was a member of the Bell Telephone Laboratories team that developed the first silicon solar energy converter.

After five years on the technical staff at Bell Labs, he joined Hoffman in 1956 and has been vice president-research and development of the Semiconductor Division since that time.

A graduate of Temple University and Massachusetts Institute of Technology, he has received the B.A. and Ph.D. degrees in physics.

He is the author of 15 papers on semiconductor materials and devices. As a coauthor he was awarded the Marconi Premium by the British Institution of Radio Engineers for the "outstanding contributions on an engineering subject" published in the British I.R.E. Journal during 1958.

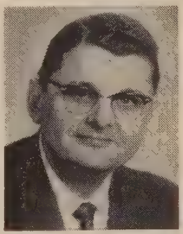
He also is a member of the American Physical Society and the Electrochemical Society.

Mr. Paradise is the founder of National Fabricated Products, Inc., acquired by Hoffman in 1955. It became the nucleus of the company's Semiconductor Division which has been headed by Paradise until now.

This division produces and markets a broad line of silicon semiconductor products including control and rectifying devices, solar cells, transistors and tunnel diodes.

⁂

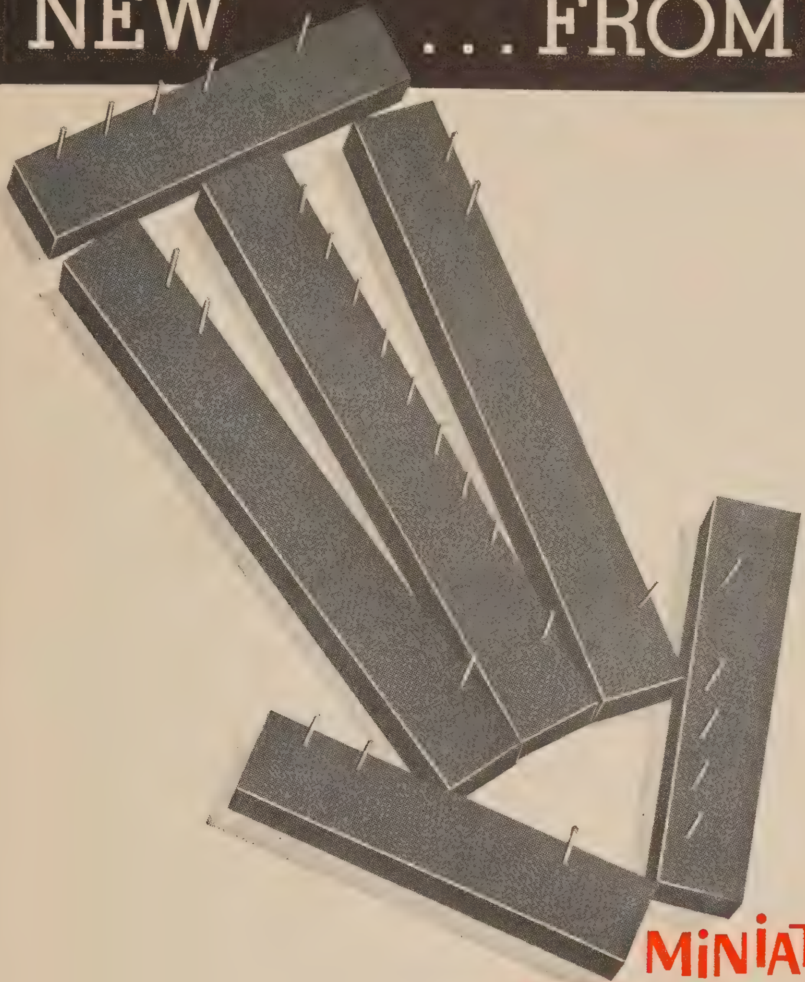
The appointment of **John F. Price** (A'42–M'55) as engineering manager for the West Coast Division of the Military Electronic Operations of Allen B. Du Mont Laboratories, Inc., is announced by E. F. Phillippi, Jr., manager of the company's West Coast Division.


J. F. Price

Before his association with Du Mont, Mr. Price was engineering supervisor of special tests and instrumentation for the Missile Division of North American Aviation where he participated in the Hound Dog and Navaho missile programs. From 1951 to 1955, he was head of the electro-physics department of Reed Research Inc., and

(Continued on page 60A)

NEW . . . FROM ESC



MINIATURE MODULAR COMPUTER DELAY LINES

. . . designed for printed board mounting

Module No.	Delay	Size
15-89	100 musec.	⅜″ x ½″ x 3⅝″
15-90	75 musec.	⅜″ x ½″ x 3⅝″
15-91	20, 10, 10, 5 musec.	⅜″ x ½″ x 3⅝″
15-92	50 musec.	⅜″ x ½″ x 2⁵⁄₁₆″
15-93	20, 20 musec.	⅜″ x ½″ x 2⁵⁄₁₆″
15-94	10, 5 musec.	⅜″ x ½″ x 2⁵⁄₁₆″

As a group these miniature, modular, lumped constant delay lines constitute an adjustable delay line. They offer great flexibility in design by providing adjustable delays ranging from 5 musec. to 335 musec. or greater, if additional units are employed.

Impedance — 93 ohms with a maximum pulse attenuation of .5 db and pulse rise time of 30 musec. (max.) for any module.

Modules with variations of rise time, delay or impedance can be supplied upon request.

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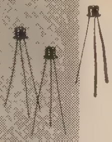

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IRE People

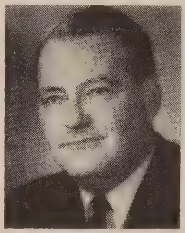
(Continued from page 58A)

from 1949 to 1951 was employed by the Naval Ordnance Laboratory where he developed an accurate F.M. pressure-time measuring system for measurement of air blast from nuclear explosions.

He received the B.S. degree (physics) from the Catholic University of America in (1946 and the M.S. (physics) from that University in 1948. He also has pursued advanced courses in electromagnetism and circuit theory, research management and space technology.

Mr. Price is a member of the Society of Photographic Engineers and Sigma Xi.

❖



G. W. Rhein

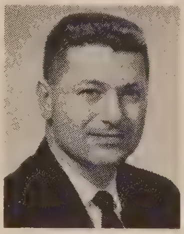
G. W. Rhein (M'48) has been appointed a product manager for Edwards Company, Inc. Formerly a vice president of Audio Teaching Center, Inc. and president of Rhein Sound Systems, Inc., both of New Haven, Conn, he has spent more than 25 years in the electronics industry. He began his career in the early 1930's, pioneering in the design, development and management of radio stations.

During World War II, he served as equipment engineer for Mackay Radio, responsible for installation of armed forces transmitters throughout Europe. Later he became government contract divisional manager for Jackson Electric Instrument Company.

An engineering consultant, he has worked in close cooperation with government and educational agencies to develop standards for audio-visual teaching equipment.

Mr. Rhein is a native of West Salem, Ill., and attended Southern Illinois University.

❖



H. F. Schunk

Henry F. Schunk (A'53–M'59), manager of Raytheon Company's Semiconductor Division training center and plant in Lewiston, Maine, has been promoted to division sales manager.

As sales manager for the division, he will direct sales of Raytheon transistors, rectifiers, diodes and Circuit-Paks to semiconductor users throughout the nation. He will also be a member of the division management committee.

Before setting up the Lewiston opera-

(Continued on page 62A)

FAIRCHILD

2N696 → 2N717
2N697 → 2N718

NEW NUMBERS
SAME CONVENIENT SOURCES

The new Fairchild 2N717 and 2N718—like other new Fairchild types—are available for immediate delivery from distributors at announcement. For quantities 1 to 999, call your nearest distributor. For quantities of 1,000 and over, contact your local Fairchild office.

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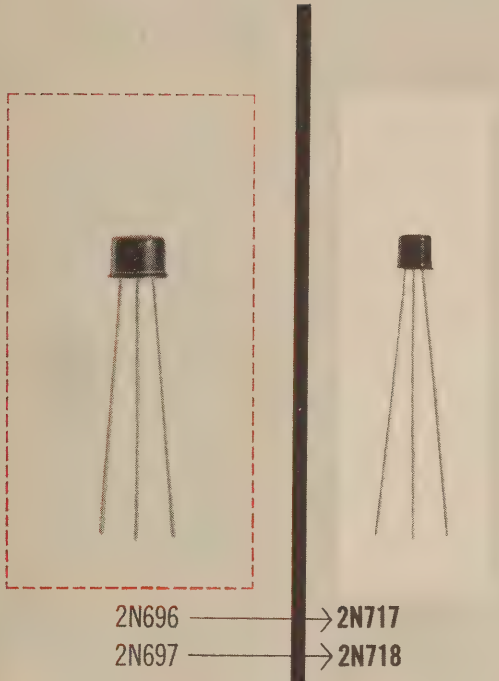

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These new types are options. Fairchild, as the originator of the 2N696 and 2N697, remains your best source for these most reliable types.

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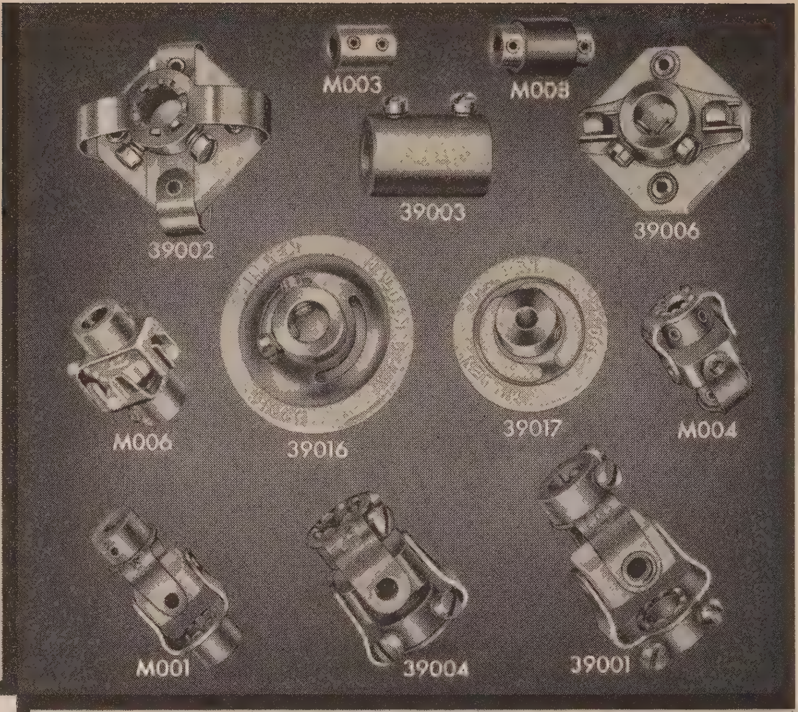

COUPLINGS

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MALDEN
MASSACHUSETTS

IRE People

(Continued from page 60A)

tion, he was manager of the Semiconductor Division plants in Newton and Brighton, Mass. He joined Raytheon in 1957 as a chief product engineer working on transistors and related devices. Prior to that he had directed the digital computer section for Ultrasonic Corporation and had been a senior engineer for Armour Research Foundation. He also served as an electrical engineer for International Business Machines Company in Poughkeepsie, N. Y.

A graduate of College of the City of New York and the University of Alabama, Mr. Schunk also studied at Loudborough Technical College, Loudborough, England.

⁂

Donald B. Sinclair (J'30–A'33–M'38–SM'43–F'43), formerly vice president and chief engineer of the General Radio Company, was appointed executive vice president and technical director at a meeting of the board of directors, held at the plant on March 3, 1960.

At the meeting, Arthur E. Thiessen, formerly vice president, was named chairman of the board. **Ivan G. Easton** (S'39–A'41–SM'45), formerly engineering manager, was appointed vice president for engineering, and **Harold M. Wilson** (SM'46), formerly manufacturing manager, was named vice president for manufacturing.

Mr. Sinclair, Mr. Thiessen and Charles C. Carey were reelected directors at the annual stockholders' meeting, also held at the plant on March 3. Lawrence H. Pexton and John D. Quackenbos were elected treasurer and clerk of the company, respectively.

Mr. Carey will continue as president and chairman of the management committee.

⁂

Robert J. Sippel (M'60) has been promoted to the position of development engineer in Mechanical Device Development at the IBM Poughkeepsie Product Development Laboratory. He is in charge of the development of an advanced magnetic disk storage input/output system.

Mr. Sippel joined IBM in 1951 as a technical engineer in 701 development following graduation from the University of Notre Dame with the B.S.E.E. degree. In 1953, he became a customer engineer on the IBM 701 at World Headquarters, returning to Poughkeepsie in 1954 to work on the design of a tape system. He was advanced to associate engineer in February, 1955, to staff engineer in March, 1956, and was promoted to project engineer in November, 1956. He joined the technical staff in Magnetic Tape Devices Development in February, 1958, and in November, 1959, he was advanced to his present position.

Mr. Sippel is a member of the Association for Computing Machinery.

⁂

Raymond A. Skov (S'53–A'55) has been promoted to the position of advisory engineer in Communications and Controls Development, at the IBM Product Development Laboratory in Poughkeepsie, N. Y. He is engaged in technical staff work in this area.

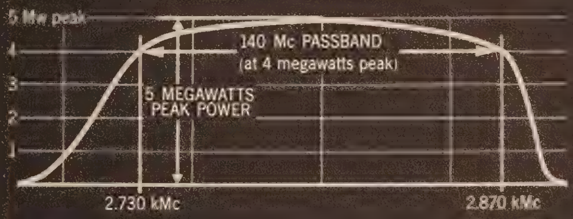
He joined IBM in 1949 as a customer engineer, a post he held until 1954, when he became a technical engineer, testing and engineering a model of a tape buffer. He also worked on field coordination of tape systems. He was advanced to associate engineer in 1955 and was engaged in engineering planning of tape systems and test evaluation of a tape transport. He became a staff engineer in 1957, joining the technical staff of the Magnetic Tape Devices Department.

He received the B.E.E. degree from the College of the City of New York in 1949 and the M.S. degree in electrical engineering from the Polytechnic Institute of Brooklyn in 1956.

⁂

Arthur F. Spero (S'49–A'50–M'55) has joined the staff of Battelle Memorial Institute's Electrical Engineering Division and is engaged in industrial electronics studies. He comes to the Columbus, Ohio, research center from Industrial Nucleonics Corporation, where he conducted development work on nucleonic devices and associated electronic equipment. A former electrical engineering research associate at the University of Illinois, Urbana, Spero has also held research and development posts at

(Continued on page 64A)



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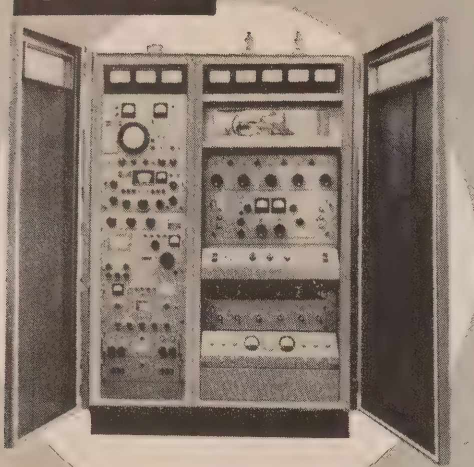

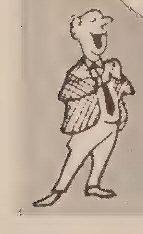

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AN/FRT-39

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IRE People

(Continued from page 62A)

Power Equipment Company and Wilmotte Manufacturing Company.

The New Battelle staff member received the B.S. degree in electrical engineering from the University of Texas, Austin, and the M.S. degree from the University of Illinois. He is a member of Eta Kappa Nu.

❖

Edward M. Tyler (A'47–M'55) has been elected assistant vice president of Hazeltine Electronics Division. He will be in charge of the Test Engineering Department.

He joined Hazeltine in 1959 after serving as General Manager of the Electronics Division of Gorham Manufacturing Co. A graduate of the University of Wisconsin, he has also been an engineer with the Western Electric Co., Bell Telephone Labs., Wired Radio, Inc., and Hogan Laboratories.

❖

C. C. Wang

Dr. Chao C. Wang (A'43–SM'49–F'57), Sperry Gyroscope Company Electronics scientist at Great Neck, N. Y., has been awarded the Victor Emanuel Distinguished Professorship at Cornell University for the Spring 1960 term, it has been announced by Dale R. Corson, dean of the College of Engineering.

Professor Wang, engineering department head for microwave tube research at Sperry, is the fourth recipient of the academic honor, awarded to "persons of broad technical competence whose interests extend into many fields of science and engineering."

Earlier recipients of the professorship, which is sponsored by the Avco Manufacturing Company, were Dr. Theodore von Karman; Balthazar van der Pol, expert in applied mathematics, and Olof E. H. Rydbeck of Sweden, an authority on upper atmosphere physics.

The purpose of the honor is to bring distinguished men "to the Campus chiefly for their ability to stimulate the (Cornell) staff both academically and professionally."

A Sperry research scientist since 1946, Professor Wang is known widely for his many basic contributions in electron physics and the microwave tube field. His work on magnetic focusing systems for electron beams and electromagnetic interaction circuits made possible the construction of extremely high-power radars for United States defense.

Professor Wang also developed mathematical techniques which permit electronic computers to yield engineering solutions to complex problems of microwave development.

He was graduated from Chiao-Tung University in Shanghai with the B.S. degree in 1936. He received the M.S. and Ph.D. degrees in radio communications from Harvard University in 1938 and 1940.

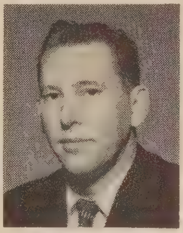
A member of the American Physical Society and the American Association for the Advancement of Science, he has published a number of papers on electronic tube theory and holds several patents.

The Avco Manufacturing Company, Inc. established the two-year visiting professorship in the College of Engineering, Cornell, in the fall of 1957, to be known as the Victor Emanuel Professorship, honoring Victor Emanuel, Cornell Class of 1919, who is a trustee of the University.

◆

Laymond D. Wann (A'54) has been promoted to research group leader of the electronics group in Continental Oil Company's research and development department.

He was a member of the research staff at Oklahoma State University, Stillwater, where he received the B.S. degree in physics in 1949 and the M.S. degree in 1950. He was employed by Continental Oil Company in 1951 as an associate research engineer in the production research division, research and development department. He was later transferred to the research services division, where he has supervised the activities of the electronics group since 1957.



L. D. Wann

◆

Seymour Weiner (S'48–A'50–M'55) has been advanced from Product Planning Manager to Product Engineering Department Head at the Sperry Semiconductor Division, Edmund G. Shower, Division Production Engineering Manager, has announced. In his new capacity Mr. Weiner will be responsible for engineering all products from the pilot shop phases into production.

S. Weiner

Prior to joining Sperry in August, 1959, he was Chief Electronic Engineer for the Olivetti Corporation of America Research Center. He has also held the position of Senior Engineer at the White Development Corporation.

A graduate of Cooper Union, Mr. Weiner received the Bachelor of Electrical Engineering degree in 1950. He has also completed advanced study at Columbia University and the University of Connecticut. He is a member of the American Insitute of Electrical Engineers and Tau Beta Pi. He has participated in the preparation of several technical papers in the field of infrared spectrometry. He served as a First Lieutenant in the U. S. Army Air Force during the Second World War.

◆

Harold A. Wheeler (A'27–M'28–F'35), president of Wheeler Laboratories, Inc., Great Neck, N. Y., received from George Washington University the 1960 Distinguished Engineer Alumnus Award, at ceremonies in Washington, D.C., Wednesday evening, February 24, 1960. Mr. Wheeler, a nationally recognized expert on radio and electronics, delivered the annual Frank A. Howard Lecture to members and friends of the Engineer Alumni Association. He spoke on the subject of radio communication with submarines.

The Distinguished Engineer Alumnus Award is given annually to a graduate of the George Washington Engineering School who has made notable contributions to his profession. Mr. Wheeler graduated from George Washington in 1925 with the B.S. degree in Physics, then awarded by the School of Engineering. He went on to post-graduate studies at Johns Hopkins University.

He began his professional career with Hazeltine Corporation in 1924, while attending George Washington. He was promoted in 1939 to vice president and chief consulting engineer of Hazeltine Electronics Corporation. After the war, in 1947, he organized Wheeler Laboratories, Inc., which has grown to a prominent engineering organization specializing in microwaves and antennas for radar and guided missiles. This company has recently become a subsidiary of the Hazeltine Corporation, and Mr. Wheeler is serving also as a Vice President and a Director of Hazeltine.

Many techniques now used in radio, television and military electronics resulted from developments by Mr. Wheeler. Among these are the diode detector and automatic volume control (AVC), which has been used in radio receivers since 1929. For his contributions to TV, he was awarded the Morris Liebmann Prize in 1940 by the IRE. He received the Navy Certificate of Commendation after World War II for his contributions to IFF (identification-friend-or-foe) radar. He has been granted 180 U. S. patents and many foreign patents. He is a Fellow of the American Institute of Electrical Engineers, and an Associate Member of the Institution of Electrical Engineers of Great Britain.

◆

Increased importance of the Palo Alto Research Laboratories of Link Division, General Precision, Inc. was recognized last week, with the election of **Hugh M. Williams** (M'53–SM'55) as Vice-President of Link.

Formerly with the Martin Company in Orlando, Florida as Manager of the Airborne Electronics Department, he assumed his duties as director of Link—Palo Alto in April, 1959. Previously he was associated with Melpar, Inc. and the RCA-Victor Division, serving in various engineering and executive capacities. He is a graduate of the University of South Caro-

H. M. Williams

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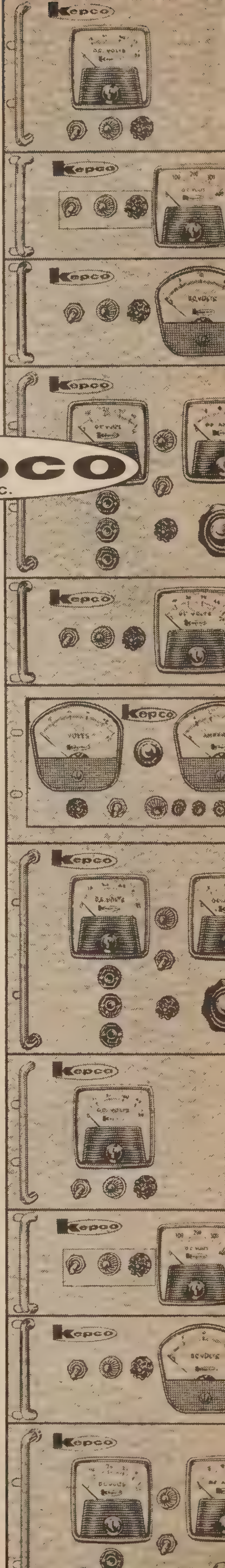

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TUNNEL DIODE NOISE PROBLEMS

by
Dr. Walter K. Volkers,
Millivac Instruments Division,
Cohu Electronics, Inc.,
Schenectady, New York

Always on hand to spoil a new amplifier's glorious entrance to the engineering field are two electronic "delinquents" that persistently demand our attention. One is *impedance*, the other is *noise*.

The *transistor* — as you undoubtedly recall — turned out to be a considerable disappointment at the time of its first blush. Its input impedance was low — its noise sky high. Many years went by before there was even a promise of surmounting these setbacks. Yet, today, they are well on the way to being solved. High input impedances are being obtained by suitable circuitry and low noise is being attained through "hushed transistor operation." *

In the *tunnel diode* — the most recent comet in the sky of electronic amplifiers — we are again being plagued by the old basic problems. It has an input impedance which is startlingly low (even lower than that of the transistor); its noise (at this time) is disturbingly high. Yet, judging from past experience, we can be reasonably certain that this new arrival will overcome these difficulties as well as the transistor (its predecessor) did. However, keep in mind, that suitable instrumentation is needed to analyze and solve the problems of every newcomer — and that it is incumbent on the "older brothers" to "tutor" the young child.

You will find a classic example of how this helpful role works in our ultra-sensitive transistor voltmeters (2 uV lowest possible reading) and in the "hushed transistor amplifiers", which we developed against overwhelming odds, several years ago.

These low-noise devices now stand ready to help the newly-born tunnel diode infant by analyzing and helping to reduce its early, lusty "noise cries", so that it can eventually assume its rightful place in the family of well-groomed amplifiers.

Millivac's low-noise amplifiers are becoming increasingly popular in a variety of fields — and especially where noise problems are severe. They are available with high or low input impedance, high or low frequency response in strictly AC, or both AC and DC types.

* Millivac's VS-64A Hushed Transistor Amplifier has less than 0.5 uV RMS noise voltage over a 60 KC passband, less than 0.2 uV with 10 KC bandwidth.

IRE People

(Continued from page 65A)

lina, and a member of the American Rocket Society.

Expansion of the Palo Alto facility and plans for new plant construction in Stanford Industrial Park were announced in December. Currently, Link employs approximately 250 persons in Palo Alto, with growth contemplated to a level approaching 1000.

⁂

Vaughn D. Winkler (A'53–M'58) has been promoted to development engineer in the Systems Engineering Department of Advanced Computational Systems at the IBM Product Development Laboratory, Poughkeepsie, N. Y. In his position, he is in charge of the implementation of the instruction unit of an advanced data system.

He joined IBM as a customer engineer in 1951 and was successively located in Washington, D.C., Hartford, and Detroit. He transferred to Poughkeepsie as a technical engineer in 1953 where he became engaged in field liaison for the IBM 702 data system. He was advanced to associate engineer in 1955 and to staff engineer in 1956. He was engaged in maintenance and reliability on another advanced system and was later active in packaging operations on standard modular system single and double card circuit units.

Mr. Winkler is a graduate of the University of Pittsburgh, Pittsburgh, Pa. with the B.S.E.E. degree.

⁂

Thomas E. Wohr (M'58) has been promoted to development engineer in the Systems Engineering Department of Advanced Computational Systems at the IBM Product Development Laboratory, Poughkeepsie, N. Y. In this position, he is in charge of the design, construction and testing of the control and maintenance areas of an advanced data system.

Mr. Wohr joined IBM in 1949 as a customer engineer, coming to Poughkeepsie in 1952, where he was engaged in release engineering. In 1954, he advanced to design engineer engaged in development of two new systems. Promoted to associate engineer in 1955, he worked on the design of an accounting system. He was promoted to staff and project engineer in 1956 and has worked from that time until his recent promotion in the areas of logic implementation and design of IBM 7000 series of computers and card testing and power distribution for another advanced data system.

Mr. Wohr is a graduate of Tufts College with the B.S.E.E. degree.

⁂

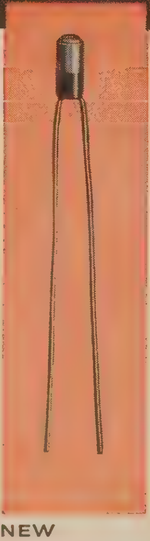
Robert Yereance (SM'59) has joined the staff of Battelle Memorial Institute's Reliability Engineering Division. He comes to the Columbus, Ohio, research center from North American Aviation in Los Angeles, Calif., where he was engaged

(Continued on page 68A)

Two Tiny Tantalums!
Smallest Ever Made
NEW SIZE TK
(On head of pin, magnified 15 times)
.060" x .150"
NEW SIZE HK
(On head of pin, magnified 15 times)
.075" x .150"
OHMITE
Tan-O-Mite* Tantalum Wire Capacitors

Now you can scale down your circuits still further. These new Ohmite tantalum wire capacitors are the smallest of their type ever produced. And, like all Ohmite tantalum capacitors, they must pass severe performance tests in Ohmite's laboratory under conditions similar to official ASESA qualifications.

Ohmite Series TW tantalum wire capacitors provide amazingly high capacitance for their size. Compared to aluminum electrolytics, they offer smaller size, longer shelf life, better electrical stability, and superior performance under temperature extremes. The anode is specially processed tantalum wire; the cathode is a silver case which also contains the electrolyte. Operating range is –55°C to +85°C. Power factor less than 50%. DC leakage current is less than .09 ua/mfd/v for units of 0.5 mfd and up; less than 0.4 for units under 0.5 mfd. Capacitances from .01 to 80 mfds; voltage ratings to 150. Many stock sizes are available as well as made-to-order units. *Write for Bulletin 148*. Tantalum foil and slug capacitors also available.



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TERMINATION
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all Series TW
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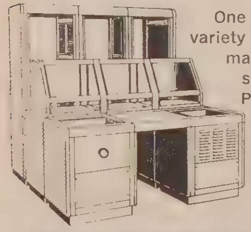

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IRE People

(Continued from page 66A)

in the evaluation of electronic components. A former member of the University of Arizona's electrical engineering faculty, his industrial experience has also included engineering assignments with the General Electric Company and Boeing Airplane Company.

The author of several papers on electronic reliability, the new Battelle staff member is credited with a patent on an electrostatic air cleaner. He received the B.S. degree in electrical engineering from Worcester Polytechnic Institute, Worcester, Mass., and has done graduate work at Kansas State University and the University of Arizona. He is a member of the American Institute of Electrical Engineers.

❖

Herbert W. Bass

North Atlantic Industries, Inc., Plainview, N. Y., has announced the appointment of **Herbert W. Bass** (M'55) as Regional Sales Manager for the Company's eastern United States marketing area.

In the newly created post, he will be responsible for sales activities in an area that includes the major portions of New England, the Central Atlantic and Southeastern states. In addition, he will assist John A. Gregorio, General Sales Manager, in general sales assignments on a national basis, including market development and research directed toward expanding the applications of the company's line of phase angle voltmeters, ratio measurement instruments and servo data conversion systems.

Prior to joining North Atlantic, he served in a number of engineering and sales capacities in the fields of missile support, microwave and avionics equipment. During the past three years he worked as a manufacturer's representative in the northeast and southeastern states.

❖

A. P. H. Barclay, General Manager (Engineering and Manufacturing), Professional Equipment Division, Philips Electronics Industries Ltd. has announced the appointment of **Roy L. Adams** (SM'55) as head of the Projects Section of the Engineering Department of this Division. This Section consolidates activities associated with the translation of customers' new requirements into technical proposals and specifications. Its activities encompass the Company's Communications, Industrial and Specialty Electronics, equipment and capabilities.

Mr. Adams has a background of research, development and production experience, with Governmental and Industrial organizations. He is an Electrical Engineering graduate from the University of Toronto and a member of the Ontario Association of Professional Engineers and the Canadian Aeronautical Institute.

❖

Hoffman Electronics Corporation has begun construction of a new Science Center in Santa Barbara as another step in its concentration on proprietary product development.

A 15,000 square foot building—located on a 10-acre site atop TV Hill, one of the highest points in Santa Barbara—is scheduled for completion in July, it was announced by H. Leslie Hoffman, president.

"The new facility," he said, "will enable the company to step up its product-oriented research in all areas of electronics, particularly in solid-state electronics.

"Expansion of this activity is part of our long-range plan to use applied science in gaining a proprietary position for the company in new products."

In addition to investigations into solid-state materials and components applications, the Science Center currently is doing applied research in industrial electronics and in satellite and anti-submarine warfare systems, Mr. Hoffman explained.

The building now being constructed will accommodate 50 scientists and supporting personnel. It is designed for future expansion and can be tripled in size.

Each scientist at the Hoffman Center will have an office next to the laboratory in which he will be going most of his work. A patio will be in the area between the laboratory wings, and at one side will be a heated swimming pool.

The site overlooks all of the city of Santa Barbara and a large part of Santa Barbara Bay. It is at the crest of Miramonte Road, 400 feet above sea level, and also can be reached by a new road now being completed.

Since its establishment in Santa Barbara early in 1959, the Science Center has been in temporary quarters at 415 East Montecito Street.

Directing its activities is **Dr. Lloyd T. DeVore** (A'42–SM'54–F'52), a vice president of the parent corporation and also director of engineering in the company's Military Products Division.

❖

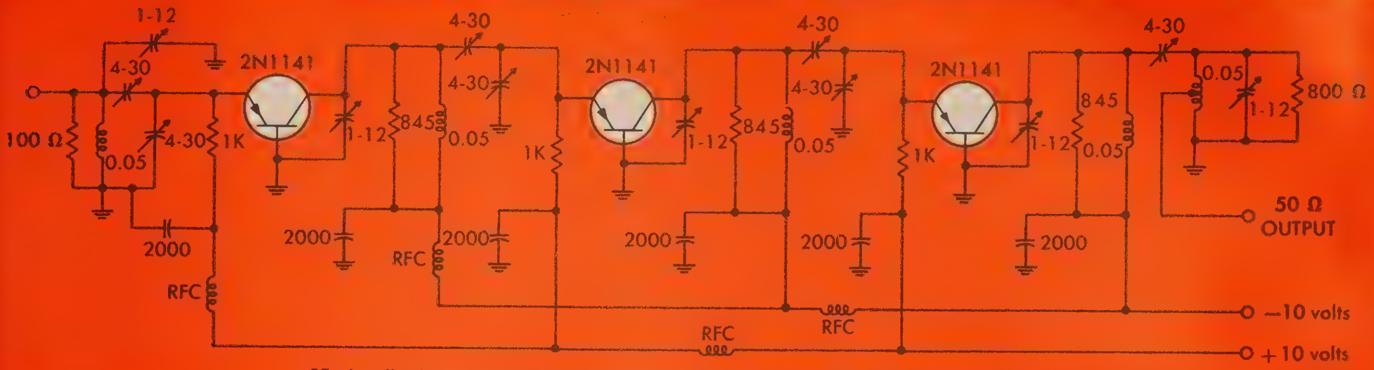
A new department has been formed by the Radio Corporation of America to meet the growing needs for magnetic tape recording devices in television broadcasting, business data processing, remote control telemetering and the nation's space program, C. H. Colledge, General Manager, RCA Broadcast and Television Equipment Division, announced today.

Known as the RCA Electronic Recording Products Department, the new unit will be headed by **M. A. Trainer** (A'35–SM'49), who joined the company in 1930 and who played an important role in the development program leading to the all-electronic television system, Mr. Colledge said.

(Continued on page 70A)

30 db gain in 200 mc RF amplifier

30 DB GAIN 16 MC BANDWIDTH IN 200 MC RF AMPLIFIER


1-12
4-30
2N1141
100 Ω
0.05
4-30
1K
2000
RFC
4-30
4-30
1-12
845
0.05
2000
RFC
2000
1K
2N1141
4-30
4-30
1-12
845
0.05
2000
2000
RFC
RFC
1K
2N1141
4-30
0.05
1-12
845
0.05
800 Ω
1-12
2000
50 Ω
OUTPUT
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+10 volts

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All Resistors are TI MIL-Line Precision Carbon Film; All RFC's encapsulated and self resonant @ 200 mcs.

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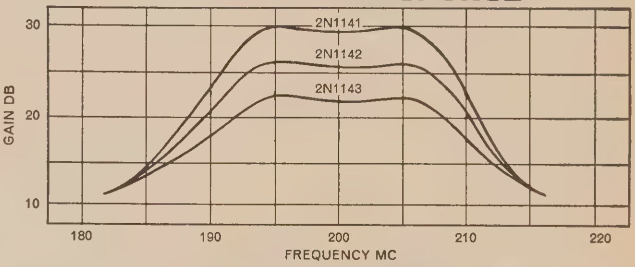
These devices are backed by *more than 3,500,000 unit hours* of life test reliability data . . . see curves below.

TYPICAL RF RESPONSE

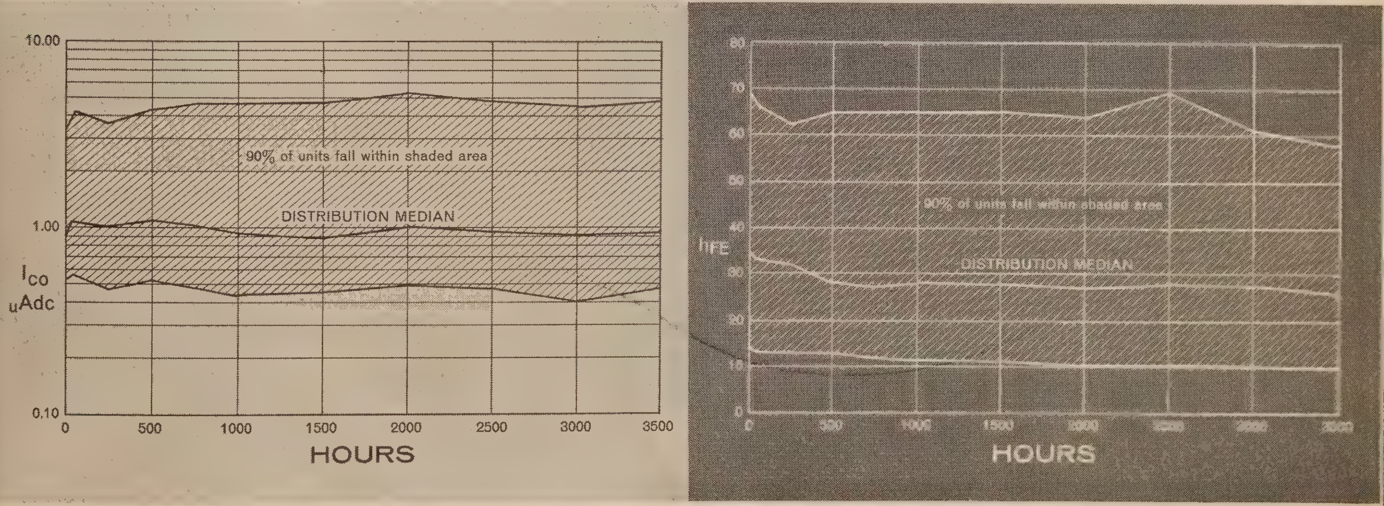


TYPICAL CHARACTERISTICS AT 25°C

	2N1141	2N1142	2N1143	unit
$f_{\alpha b}$	750	600	480	mc
C_{Tc}	1.2	1.4	1.5	µµf
r_b'	65	80	110	ohms

UNIT TYPE 2N1142: I_{CBO} AND h_{FE} VS HOURS OF STORAGE AT +100°C

TEST LEGEND: Sample Size: 1000 units ▪ Test Condition: Storage at +100°C ▪ I_{co} Measured at: $V_{CB} = -20v$, $I_E = 0$ ▪ h_{FE} Measured at: $V_{CE} = -6v$, $I_C = -10ma$



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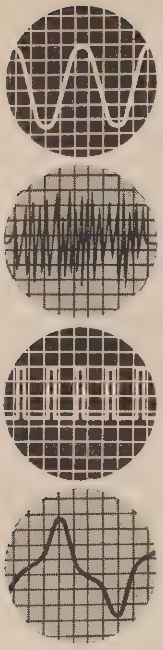

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CALIBRATOR STABILITY: 0.5% for line variation 105-125 volts

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measures from

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regardless of waveform

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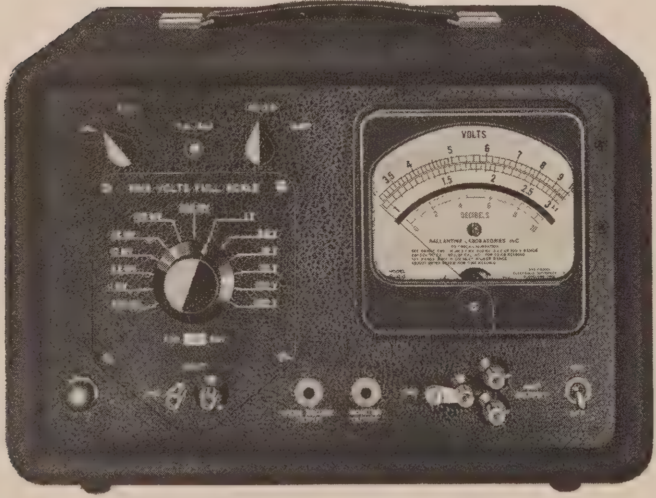

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(Continued from page 68A)

Mr. Trainer has been serving as Manager, Market Development for the RCA Broadcast and Television Equipment Division. During World War II, he was Supervising Engineer of RCA's Television Terminal Equipment Section, engaged in designing airborne television equipment and television-guided missiles for military purposes.

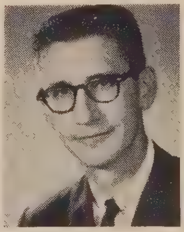
He is a graduate in electrical engineering of the Drexel Institute in Philadelphia, Pa. He is a member of the Tau Beta Pi and Phi Kappa Phi honorary engineering societies, the Society of Motion Picture and Television Engineers and the Franklin Institute, and has been a member at various times of industry committees dealing with television broadcasting problems.

Serving as Marketing Manager for the new department will be **Jerome L. Grever** (S'50–A'51–M'56). With RCA for the past 11 years, he obtained his electrical engineering degree at the University of Louisville and his master's degree at Purdue University. He is an active member of the SMPTE.

Heading the Department's engineering activity is **A. H. Lind** (S'42–A'50–M'56), who has specialized in studio television and audio equipment since coming to RCA in 1946. He received the B.S. and M.S. degrees in electrical engineering from the University of Wisconsin. He is a member of the Eta Kappa Nu and Tau Beta Pi engineering societies, and SMPTE.

❖

James L. Pyle (S'49–A'52–M'57) has been appointed Manager, Government Relations, for the Technical Products Division of Packard Bell Electronics. Applications Engineers at Packard Bell offices in Dayton, Washington, Rome (N. Y.), Seattle and Los Angeles will report to him.



J. L. Pyle

He has most recently served in Los Angeles as assistant to the director of sales and administration. Before that, and since 1955, he was manager of the Dayton, Ohio office of the Los Angeles electronics firm.

Before joining the company, he was a project engineer with the U. S. Air Force stationed at Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, and Hamilton Air Force Base, California. During World War II he served four years as an electronics technician in the Air Force.

Mr. Pyle was graduated from St.Louis University with the B.S. degree in electrical engineering. He is a registered professional engineer (Missouri).

❖

(Continued on page 72A)

Professional Group On Audio

The IRE Professional Group on Audio is the oldest and one of the most active Groups in the IRE. Formed on June 2, 1948, the Audio Group now serves the specialized technical needs of over 5000 Group members who wish to keep abreast of progress in communication at audio frequencies, the audio portion of the radio frequency spectrum, and recording and reproducing.

Perhaps the most important activity of the Group is its technical publication, called TRANSACTIONS, which is sent bi-monthly to all Group members who have paid the $2 assessment. The TRANSACTIONS provides an invaluable source of authoritative information concerning the latest developments in the audio field. In addition to technical papers, the TRANSACTIONS contains informative technical editorials and news items pertaining to the audio field. To date, Group members have received 55 issues comprising 1750 pages of material devoted to their specific field of interest.

In addition to its publication activities, the Group sponsors technical sessions for the benefit of its members who attend national meetings, such as the IRE International Convention, the National Electronics Conference and the Wescon.

Supplementing its program of national meetings, the Audio Group has established 17 Chapters in cities throughout the country which, in cooperation with IRE Sections in those areas, hold frequent local meetings on subjects of timely interest to the audio engineer.

Thus the Audio Group, through its publications, national conferences, and Chapter meetings, renders a valuable service which no audio engineer can afford to be without.

Ernst Weber

Chairman, Professional Groups Committee

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IRE Transactions on AUDIO
IRE Transactions on Component Parts
IRE Transactions on Medical Electronics
Professional Group on Medical Electronics
IRE Transactions on Microwave Theory and Techniques
Published by the Professional Group on Microwave Theory and Techniques

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Each group publishes its own specialized papers in its *Transactions*, some annually, and some bi-monthly. The larger groups have organized local Chapters, and they also sponsor technical sessions at IRE Conventions.

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Engineering Management (G 14)	Fee $3
Engineering Writing and Speech (G 26)	Fee $2
Human Factors in Electronics (G 28)	Fee $2
Industrial Electronics (G 13)	Fee $3
Information Theory (G 12)	Fee $3
Instrumentation (G 9)	Fee $2
Microwave Theory and Techniques (G 17)	Fee $3
Military Electronics (G 24)	Fee $2
Nuclear Science (G 5)	Fee $3
Production Techniques (G 22)	Fee $2
Radio Frequency Interference (G 27)	Fee $2
Reliability and Quality Control (G 7)	Fee $3
Space Electronics and Telemetry (G 10)	Fee $2
Ultrasonics Engineering (G 20)	Fee $2
Vehicular Communications (G 6)	Fee $2

IRE Professional Groups are only open to those who are already members of the IRE. Copies of Professional Group Transactions are available to non-members at three times the cost-price to group members.

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(Continued from page 70A)

Norman J. Golden (A'51–SM'55) has been promoted to vice president-research and development of the Semiconductor Division of Hoffman Electronics Corporation.

He succeeds Dr. Morton B. Prince, who recently was named vice president and general manager of the division.

Mr. Golden has been manager of the transistor section the past year. He has had nine years experience in semiconductor research and development and is the holder of 25 patents in the field.

Before joining Hoffman, he was in charge of semiconductor operations and product development at Sylvania-Thorn, Ltd., London, England.

He received the B.S. degree, cum laude, in electronic physics from Harvard University, Cambridge, Mass. He is a member of the American Physical Society and the British Institute of Electrical Engineers.

N. J. Golden

❖

Selection of **Thomas D. Rowan** (A'52–M'57), engineering director at Remington Rand Univac, St. Paul, Minn., as one of the nation's 44 most promising young business executives was announced today by Dean Howard W. Johnson of the school of Industrial Management, Massachusetts Institute of Technology.

Mr. Rowan was the only Minnesotan chosen for an Alfred P. Sloan fellowship in executive development. He will move to the Cambridge, Mass., area in June to begin 12 months of study in the fundamentals of sound management decisions. Winners of Sloan Fellowships were selected by M.I.T. from a group of executives whose employers nominated them for admission to the program.

"Chosen early in their industrial careers, these men have a long future of service to industry ahead of them," according to John M. Wynne, director of executive development programs at M.I.T.

"Their year of study at M.I.T. will consist of a program of special courses in economics and industrial management with senior members of the faculty, supplemented by a program of field visits and management seminars in which the men have an opportunity to meet outstanding leaders in business and government."

As part of the course, Mr. Rowan's group will spend a week in Washington, D. C., where they will meet with a number of high-ranking government officials. The group will fly to Europe for a two-week tour of France, England, Belgium and Germany in May 1961 and return to M.I.T. in time for commencement exercises.

He joined Remington Rand Univac in 1950 as an assistant electrical engineer, after graduating from the Catholic University of America, Washington, D. C., with the B.S. degree in electrical engineering. He has since been promoted to positions of increasing responsibility.

T. D. Rowan

❖

Richard A. Trachy (M'56) has been promoted to the position of senior engineer at the IBM Poughkeepsie Product Development Laboratory. In his position, he is in charge of IBM 7080 Systems Engineering which includes the design, development, and release of the 7080 data system. He also directs IBM 705 III Product Engineering.

He joined IBM as a technical engineer in 1951 following graduation from the University of New Hampshire with the B.S.E.E. degree. Following work on the IBM 702, he was promoted to associate engineer in 1954 and engaged in work in the development of the IBM 705. Advanced to project engineer in 1956, he was in charge of a group engaged in IBM 705 III systems development. He was advanced to development engineer in 1957 and in this capacity has held positions as 700 Series Product Engineering Manager and later 705 III Engineering manager.

Mr. Trachy is the holder of one patent. He was employed by Western Union Telegraph Company prior to joining IBM and served in the U. S. Army during World War II.

❖

Kinetics Corporation, Solana Beach, Calif., manufacturer of electronic and electro-mechanical components for the aircraft and missile fields, has appointed **Burton M. Kuck** (S'43–A'44–M'53) senior project engineer, it was announced by Kenneth C. Stone, president. Mr. Kuck joined Kinetics in January, 1960. He was formerly with the Bell Telephone Laboratories in New Jersey, where he specialized in military communications system design and underwater sound development.

He received the B.S. degree in electrical engineering from Purdue University and completed post graduate studies in advanced electronics at the University of Cincinnati. He is a member of the American Association for the Advancement of Science, and is a life member of Eta Kappa Nu Association and Tau Beta Pi Association.

B. M. Kuck

❖

(Continued on page 74A)

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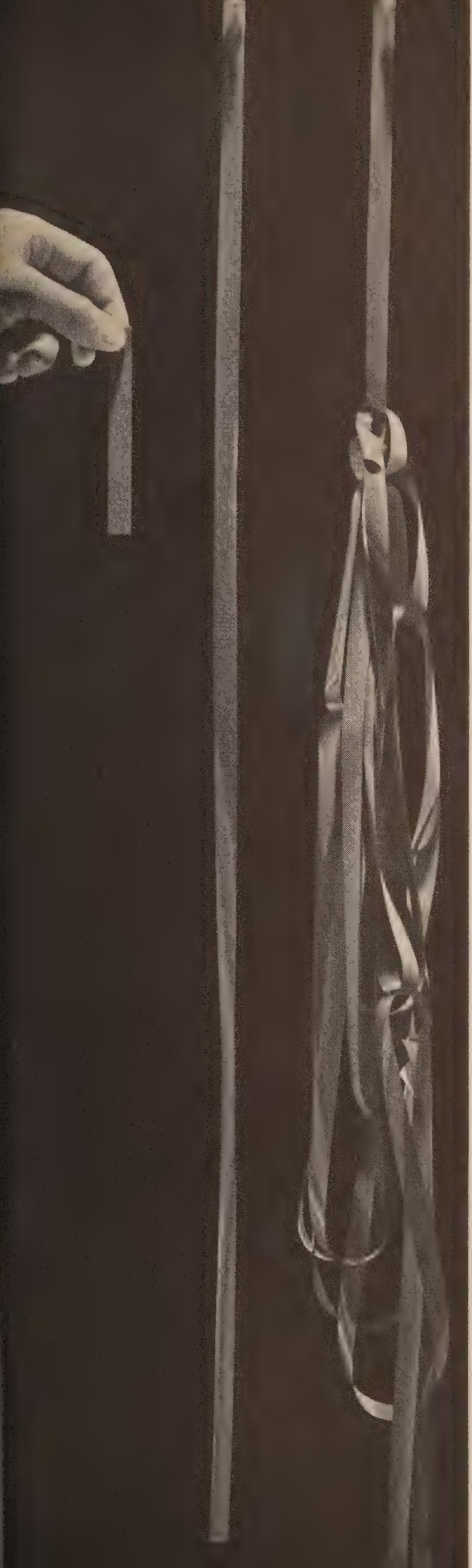


Higher Education for Computers

"Let's put the computer in at the start of a problem, rather than just having it buzz through the computations."

This is the approach being taken by computer specialists at the General Motors Research Laboratories as they explore ways of giving large-scale digital computers a greater role in the solution of problems. The object is to "teach" computers to apply the same rules men use in formulating, analyzing, and solving questions of modern science and engineering.

A recent outgrowth of this work is DYANA, GM Research's new automatic analysis and programming system. DYANA is one of the first computer systems to "understand" declarative statements. For a large class of dynamic problems, the engineer can simply describe his physical system to the computer. The computer figures out how to handle it.

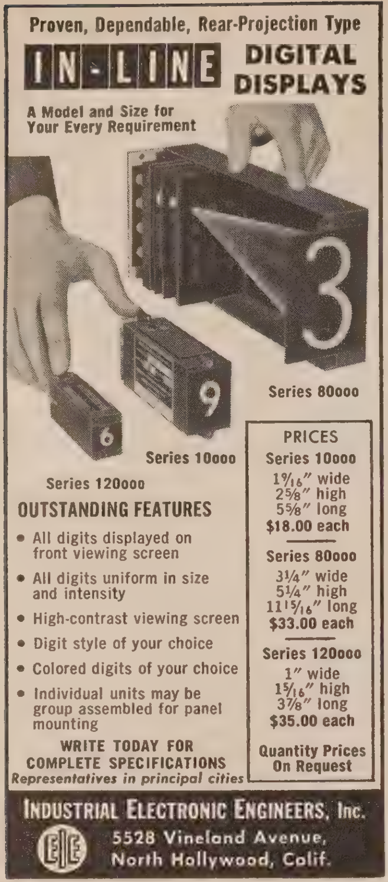
For the solution, DYANA automatically directs the computer to prepare a mathematical model of the system, to write its own program for solving the model, then to execute the program and compute the desired answers.

The higher education of computers currently involves studies in symbol manipulation, problem-oriented languages, character and pattern recognition, and engineering simulation.

Such advanced computer concepts are giving General Motors professional people more time for creative engineering and research—time to explore ideas and to develop "more and better things for more people."

General Motors Research Laboratories
Warren, Michigan

Comparison of program tapes for a vibrational problem expressed in DYANA language, in algebraic-oriented language, and in the basic machine language.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IRE People

(Continued from page 72A)

Albert K. Fowler (A'51–M'56) has been named Marketing Manager by Antenna Systems, Inc., Hingham, Mass., it was announced by Charles W. Creaser, Jr., President. Mr. Fowler was formerly Assistant Vice President of Technical Appliance Corporation, Sherburne, N. Y., where he was in charge of military sales.

A. K. Fowler

Prior to joining TACO in 1957, He was engaged in antenna design work with General Electric Company, HMEE Department, in Syracuse, N. Y. He is a graduate of Rutgers University.

❖

Dr. Harald T. Friis (A'18–M'26–F'29)(L) has been retained as a consultant by Wheeler Laboratories, Inc. of Great Neck and Smithtown, L. I., a subsidiary of Hazeltine Corporation. He retired two years ago as Director of Research in High Frequency and Electronics of Bell Telephone Laboratories, Inc.

H. T. Friis

His work at Wheeler Laboratories will be directed largely to military electronics problems related to his previous specializations, including antennas for radar and guided missile systems, waveguide applications, and low-noise, high-frequency amplifiers. He will also cooperate with various engineering groups in Hazeltine Corporation and its affiliated companies, notably Hazeltine Research Corporation of Plainview, L. I., on special electronics projects.

A native of Naestved, Denmark, he received the E. E. and Doctor of Engineering degrees from the Royal Technical College, Copenhagen, Denmark. He came to the United States in 1919 on a Fellowship from the American-Scandinavian Foundation to study at Columbia University, New York, N. Y. That year, he joined the Research Division of the Western Electric Company's Engineering Department, which became Bell Telephone Laboratories in 1925. He spent 38 years with the Bell System before retiring in 1958.

During his distinguished career, he contributed substantially to many aspects of the radio art. He has made many contributions in such fields as vacuum-tube efficiency, ship-to-shore radio reception, long-wave and short-wave trans-Atlantic radiotelephony, antenna design, microwave systems, waveguides, radars, and accurate methods of measuring radio signals and noise.

He is a Fellow of the American Institute of Electrical Engineers, and a member of the American Association for the Advancement of Science, the Danish Engineering Society, the Danish Academy of Technical Sciences and the American Section of the International Scientific Radio Union. He has served on the Panel for Basic Research, Research and Development Board, Washington, D. C., and on the Air Force's Scientific Advisory Board.

Dr. Friis has received various awards for his scientific contributions. They include the Morris Liebmann Memorial Prize from the IRE in 1939, the Medal of Honor of the IRE in 1955, and the Stuart Ballantine Medal in 1958 from the Franklin Institute. In 1954, he was awarded the Danish decoration, "Knight of the Order of Dannebrog," presented by King Frederick IX, and the Valdemar Poulsen Gold Medal presented by the Danish Academy of Technical Sciences.

❖

André M. Angot (SM'51), Technical Manager of the T.R.T.C. (France) has been elected Chairman of the "Societe Francaise des Radioelectriciens" for 1960.

He is a Professor of Applied Mathematics at the "Ecole Superieure D'Electricite, in Paris. Three years ago, he was a General Military Engineer, Head of the Research and Signal Manufacture Department of the French Army.

A. M. Angot

❖

Dr. Samuel B. Batdorf (SM'57), former director of Research for Lockheed Electronics Company's Newport Division has joined Aeronutronic, a Division of Ford Motor Company, as manager of Product Planning for Range Systems Operations.

Announcement of the management appointment was made by Dr. Ernst H. Krause, general operations manager of Range Systems Operations.

One of five major technical activities at Aeronutronic, Range Systems Operations provides technical and special support for the nation's missile and satellite range programs. Among other contracts, it is responsible for initial instrumentation planning for the Pacific Missile Range and through its Natick, Mass., Space Surveillance Office is acting as systems contractor on a special Air Force program concerned with cataloging and computing satellite orbits.

Dr. Batdorf originally joined Lockheed in mid-1956 at the firm's Missile Systems Division in Palo Alto, Calif., as assistant director of Research and head of the Electronic Division. Later, he was technical director of Lockheed's Satellite Projects (now known as Midas, Discoverer and Samos).

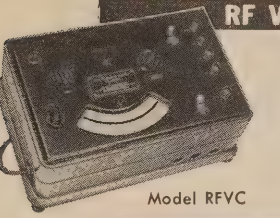
In 1958 he took a leave of absence to serve under Dr. Herbert F. York (now director of Research and Engineering in the

(Continued on page 76A)

NEW INSTRUMENTS

by Sensitive Research

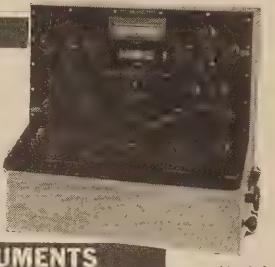
RF VOLTMETER CALIBRATOR



Model RFVC

Model RFVC — Radio Frequency Self Checking RMS voltmeter for the certification of VTVM's from DC to 10 Mc. Accuracy .3% of full scale ± .2% frequency influence. Ranges .01/.1/1/3 V. Checks its own accuracy against a .05% stable internal standard source.

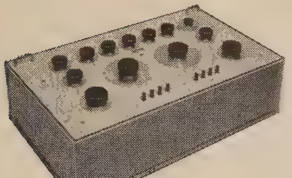
CALIBRATION CONSOLES



Model LTC

Model LTC — AC-DC/DC. Accuracy .05% of actual reading. Ranges .5 V. to 1111 V.; 1 Ma (2 Ma on AC) to 11.11 amps. Resolution .01%. Frequency range DC to 25 KC. Direct % Error Readout. Model LT-PS — AC power supply to full capabilities of console. Harmonic distortion less than .1%. Other consoles available.

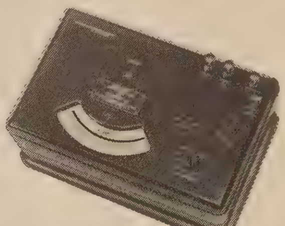
DC POTENTIOMETERS



Type 9144

A new line of 6 figure instruments guaranteed 10X more accurate than any potentiometer commercially available today, having a subdivision of 1 part in 10^6 of the 1 volt setting and calibrated to be usable to an accuracy of ± .0002% or better. Absolute accuracy guaranteed to ± .001% nominal or better. Resolution excellent for comparison of saturated standard cells. Temperature controlled. High sensitivity Galvanometer, 4 terminal NBS Type resistors, ratio boxes and other primary standards available.

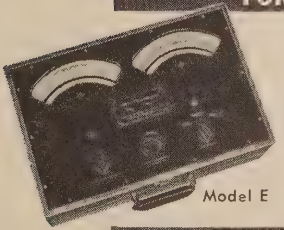
EXPANDED SCALE INSTRUMENTS



Model INCRE

Model INCRE — Differential incremeter. A NEW .05% f.s. accurate expanded scale DC standard for rack panel mounting or portable use. Combines the high comparison accuracy of the differential instrument with a .005% stable source. Scale has an effective length of 63″ or 70″, and a resolution of 1000 divisions. Each 10% of any range is expanded over the instrument's actual 6.3″ or 7″ scale length. Direct reading. No balancing or nulling. Single or multi-range combinations from 200 ua. to 30 amps. and 200 mv. to 1 kv.

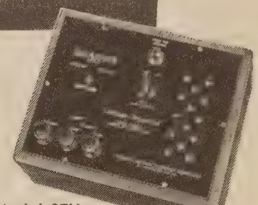
FORM FACTOR INSTRUMENT



Model E

Model E — supplies a direct reading correction factor for instruments affected by non-sinusoidal wave form deviation. Indicates ratio of true RMS values to average, positive peak, and negative peak values. Determines the true RMS values of average and peak reading instruments that are used on a distorted wave. Accuracy: .2% between 25-500 cps.

DC VOLTAGE STANDARDS



Model STV

Model STV — Nominal output 1.0000 V. and 1.0185 V. Accuracy ± .01%. Actual output certified within ± .001% and guaranteed stable within ± .005%. 115 V. 60 cps input. Unaffected by extremes of temperature, short circuiting, and vibration. Replaces the standard cell. OEM types available.

GENERAL PURPOSE PORTABLES

Model N

Model N—economically priced, stable and rugged .5% accurate DC current and voltage instrument. Long 6.1″ scale. Employs a shielded "U" shaped magnet and not the common center core type characteristic of instruments in its price range. Model NP is for panel mounting. Model NSI is an AC version. All have molded bakelite cases and are available switch controlled.

AUTOMATIC OVERLOAD PROTECTION

Model 2AP

Model 2 AP — AC-DC Polyranger. Thermocouple type. Automatically protected for overloads of at least 5000%. Accuracy: .75%. Ranges from 2 ma. to 1 amp. and 2 V. to 500 V. Sensitivity: 500 ohms/V. Diamond Pivoted. Other Polyrangers with as many as 88 ranges available.

AC-DC LABORATORY STANDARD AND POWER SUPPLY

Model THACH AND THACH-PS

Model THACH — AC/DC Self Checking Volt-Amp Milliammeter. Accuracy ± .2% f.s. to 4 kc. Ranges — 10/20/50/100/200/500 ma.; 1/2/5 Amps; 1/2/5/10/20/50/100/200/500/1000 V. f.s. Checks its own accuracy against an internal standard cell. Model THACH-PS — special regulated THACH Power Supply (optional) automatically shuts off power to the THACH when switching ranges, reducing possibility of accidental overloads. Output is DC or 60 cps. (50-2500 cps. can be plugged in). Combination serves as a calibrator, measuring instrument, and general purpose power supply.

Primary and secondary standards for the accurate measurement or certification of AC-DC current, voltage, power, power factor, frequency and magnetic quantities. All electrical indicating instruments have hand-drawn mirrored scales and most are Diamond Pivoted, of course!

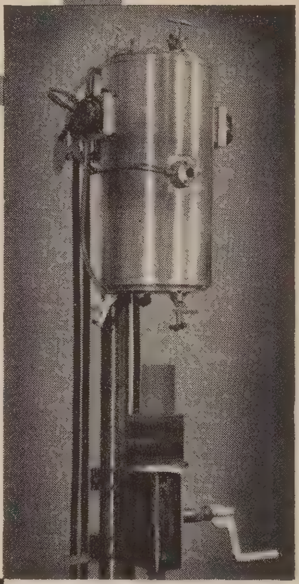
Not illustrated above, but available, are a complete line of portable and panel types including: • **Wattmeters** • **Electrostatic Voltmeters** • **Peak Voltmeters** • **Thermocouple Instruments** • **Differentials** • **Ratiometers** • **Corrosion Instruments** • **Panel Instruments** • **Test Sets** • **Fluxmeters and accessories such as Shunts and Multipliers.** All SRIC instruments have their certification directly traceable to the National Bureau of Standards and are unconditionally guaranteed.

NEW ROCHELLE, N. Y.

ELECTRICAL INSTRUMENTS
OF PRECISION SINCE 1927

Symbol of Quality

SENSITIVE RESEARCH INSTRUMENT CORPORATION



5100° F

CURTISS-WRIGHT RESISTANCE FURNACE

These resistance furnaces, designed for high temperature materials testing, can be operated continuously to 4800° F and intermittently to 5100° F. Compact graphite heating elements permit unusually large working chambers with small exterior-shell dimensions.

The units are water cooled. Atmospheric control in the working chambers is provided by a flow of helium or other inert or reducing gas.

The furnaces can be supplied with either manual or automatic control. With manual control, an optical pyrometer is used for viewing the interior of the furnace.

Descriptive literature is available on request.

Model	Working Volume
CB 213	4″ Dia. x 8″
CB 214	12″ Dia. x 15″

SANTA BARBARA DIVISION
CURTISS-WRIGHT
CORPORATION - SANTA BARBARA, CALIF.

Inquiries are solicited from qualified sales representatives for the following territories: New England, New York-New Jersey, Chicago, and Florida.

IRE People

(Continued from page 74A)

Department of Defense) at the Advanced Research Projects Agency (ARPA) in Washington, D. C., to help formulate the military space program. His first assignment was to head up the Man-in-Space Project. When the major responsibility for this passed to the newly-created National Aeronautics and Space Administration (NASA), he was appointed chairman of the Communication Satellite Program, and was concerned with the technical direction of all military communication satellite projects.

He rejoined Lockheed in his most recent position in August, 1959 and continued to serve as a consultant to ARPA.

Prior to his Lockheed affiliation, he was with Westinghouse Research Laboratories, where he served in various management and research capacities. His latest assignment was as director of development on the staff of the vice president of engineering.

Before that he was with the National Advisory Committee for Aeronautics, where he was chairman of the Committee on Advanced Study of the Langley Laboratories and a member of the NACA Committee on Aircraft Structural Materials.

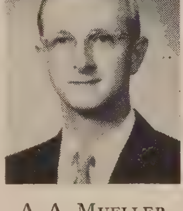
He spent three years with the University of Nevada, first as assistant professor, then associate professor, of physics.

Dr. Batdorf was born of American missionary parents in 1914 in Jung Hsien, Szechwan Province, China. He was educated in China, England and the United States, and graduated from the University of California, Berkeley, as a Levi Strauss scholar and a member of Phi Beta Kappa. He remained at the University as a teaching assistant, obtained the M.S. degree in 1936, and the Ph.D. degree in 1938.

He is a fellow of the American Physical Society, and an associate fellow of the Institute of the Aeronautical Sciences. He is also chairman of the Applied Mechanics Division of the American Society of Mechanical Engineers and a member of the New Activities Committee of the American Institute of Electrical Engineers.

❖

Andrew A. Mueller (S'46–A'48–M'55) has joined Wells Electronics Company of South Bend, Ind., as Chief Engineer. In this capacity, he will be responsible for all engineering activities including new product design and development, production engineering, and quality control. Wells Electronics, originally an IF transformer manufacturer, has recently diversified into components for the radio-telephone industry and into subminiature encapsulated networks and assemblies.



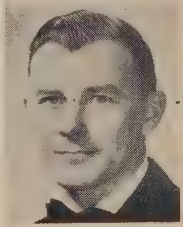
A. A. Mueller

Mr. Mueller attended Northwestern University, Evanston, Ill., where he received the BSEE degree in 1946. He also attended graduate school at Northwestern. He is the author of several technical papers, holds U. S. Patent No. 2,758,223, and is a licensed private pilot.

Before joining Wells he held key engineering positions with Mark Products Company, Morton Grove, Ill., Chicago Aerial Industries of Melrose Park, A. C. Nielsen Company of Chicago, and the Glenn L. Martin Company of Baltimore, Md.

❖

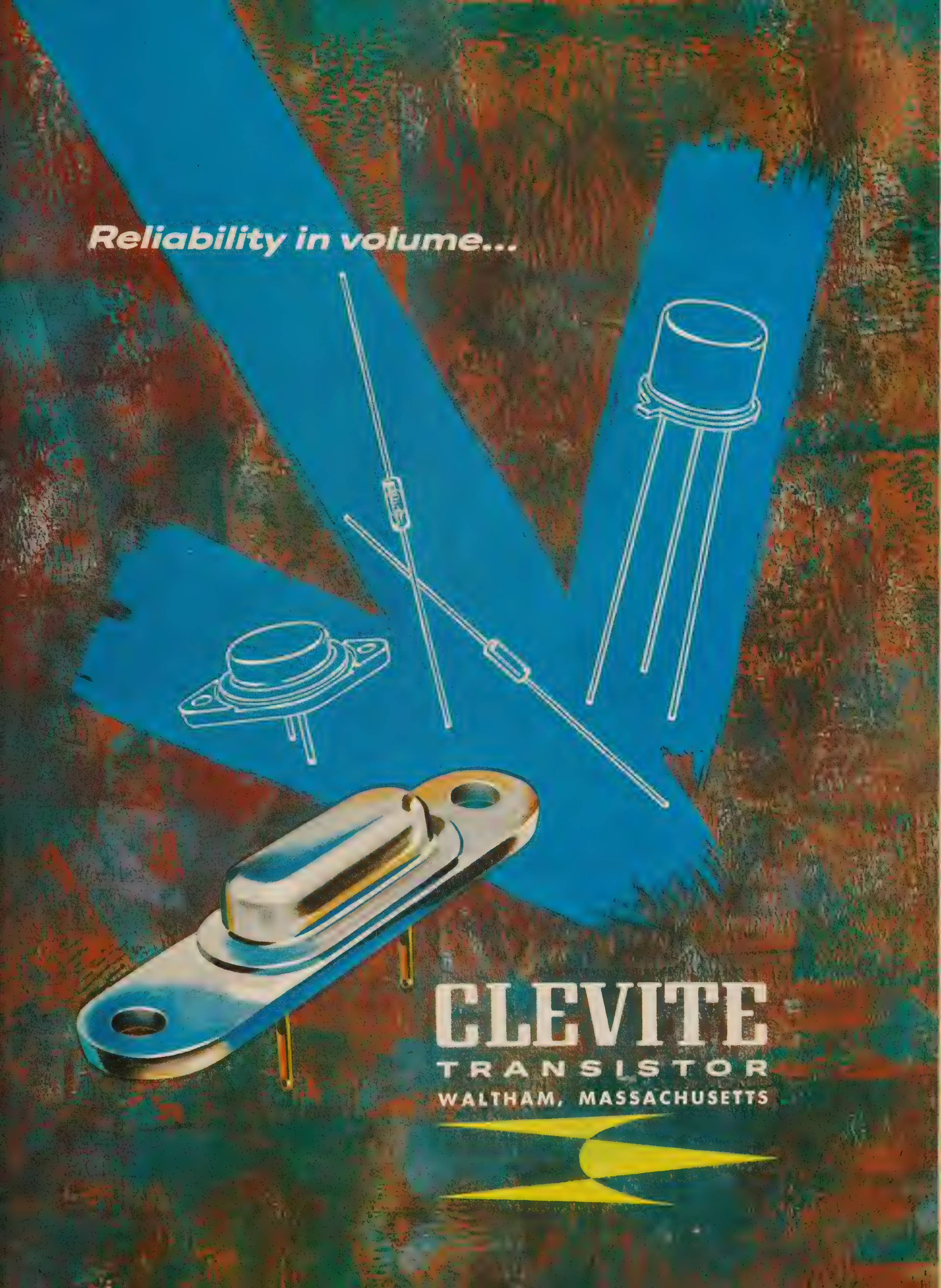
Appointment of **Dr. D. Joseph Donahue** (M'59) as Manager, Advanced Development, RCA Semiconductor and Materials Division, was announced today by E. O. Johnson, Chief Engineer.



D. J. Donahue

Dr. Donahue joined RCA in 1951 at the electron tube manufacturing plant at Lancaster, Pa. For several years, he worked on various chemical and physical activities involving the development of color picture and camera tubes. He has made many major contributions in such areas as fine-mesh screens, transparent conductive coatings, aperture

(Continued on page 79A)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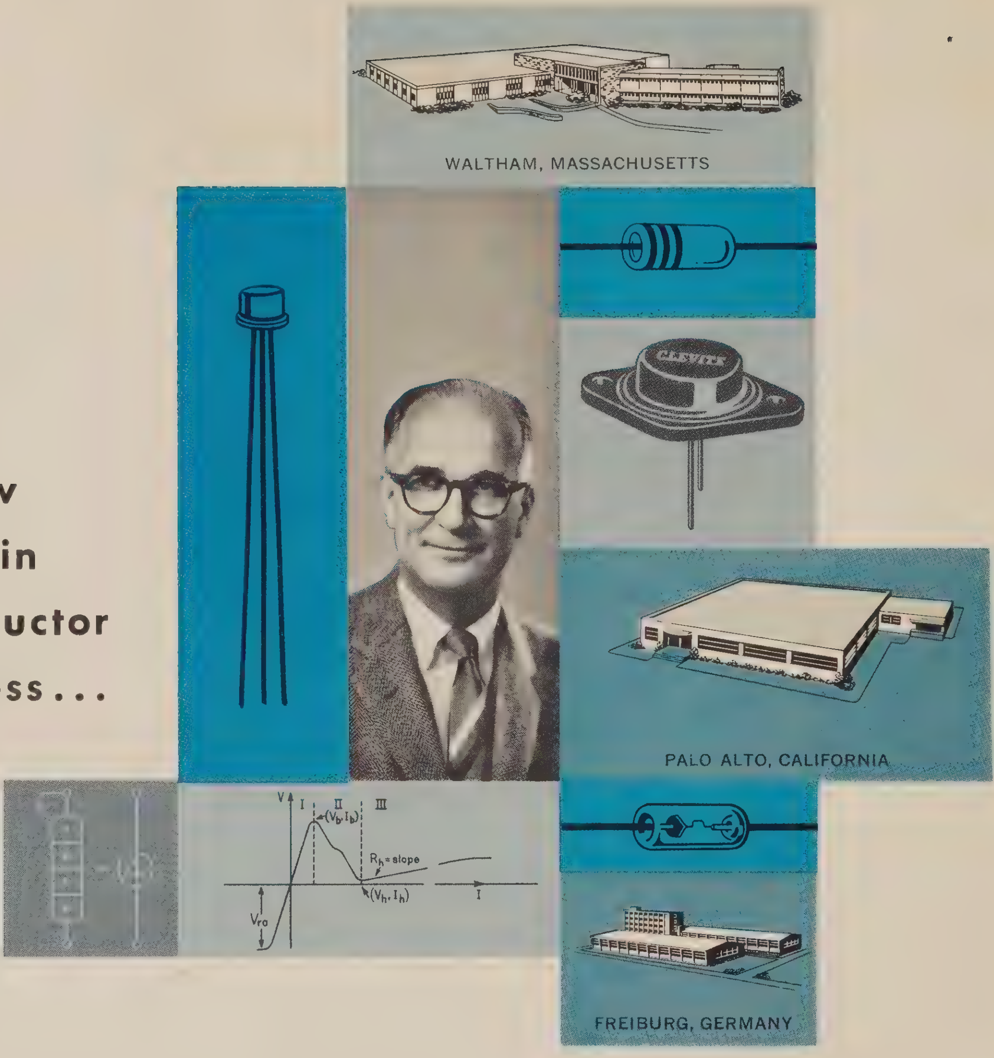
CLEVITE
TRANSISTOR
WALTHAM, MASSACHUSETTS

a new pattern in semiconductor progress . . .



SHOCKLEY TRANSISTOR JOINS CLEVITE

In keeping with its program of advancement in semiconductors, Clevite has acquired the Shockley Transistor Corporation of Palo Alto, California.

Dr. William Shockley, noted solid state physicist and co-winner of the 1956 Nobel Prize for his work in the development of the transistor, joins Clevite, together with his research and development organization.

NEW PRODUCTS

In addition to Clevite Transistor's broad line of diodes and transistors, the corporation now offers to the industry Shockley devices which represent new advances in the semiconductor art. The Shockley 4-layer diode is a nearly ideal switch for pulse generation, pulse counting and high power switching in such applications as computers, telephone and control circuits. A new plant in Palo Alto, California, is underway to fill the growing demand for these new devices.

NEW PLANTS

Besides the new plant for the Shockley organization in California, Clevite Transistor is nearing completion of its new $4,000,000 Waltham, Massachusetts facility which will employ 2,000 people. The present Waltham plant will continue as a supplementary operation. Clevite's overseas operation, Intermetall G.m.b.H., now employs 1,000 people in a new plant at Freiburg, West Germany to serve the European market.

To find out more about our progress and our products, write:

Reliability In Volume . . .

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CORPORATION

CLEVITE TRANSISTOR

254 Crescent Street Waltham 54, Mass. Tel: TWinbrook 4-9330

SHOCKLEY TRANSISTOR UNIT — STANFORD INDUSTRIAL PARK, PALO ALTO, CALIFORNIA

(Continued from page 76A)

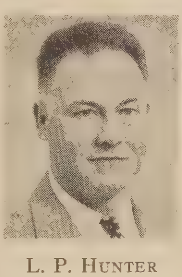
masks and the application of phosphor screens.

In 1958, he was transferred to the RCA Semiconductor and Materials Division. As a Manager in the Advanced Development activity, he was responsible for semiconductor chemistry and physics, including new device work on gallium arsenide solar cells and parametric diodes. Dr. Donahue and his associates have had a major role in the development of the RCA tunnel diode, a tiny miniature electronic component for satellites, space vehicles and electronic computers. He also has made extensive investigations in the study of semiconductor surfaces, diffusion masking, purification of gallium and arsenic, and solid-state measurements.

A native of Lemont, Ill., Dr. Donahue received his degrees in Physical Chemistry from the University of Michigan. He is a member of the American Chemical Society and Electrochemical Society. He is the author of several technical articles on new advances in the semiconductor art.

❖

Dr. Lloyd P. Hunter (SM'52) formerly resident manager of the Poughkeepsie, N. Y., Research Laboratory of the International Business Machines Corp., has joined the corporate staff of the company on special assignment at its New York, N. Y., world headquarters.



L. P. Hunter

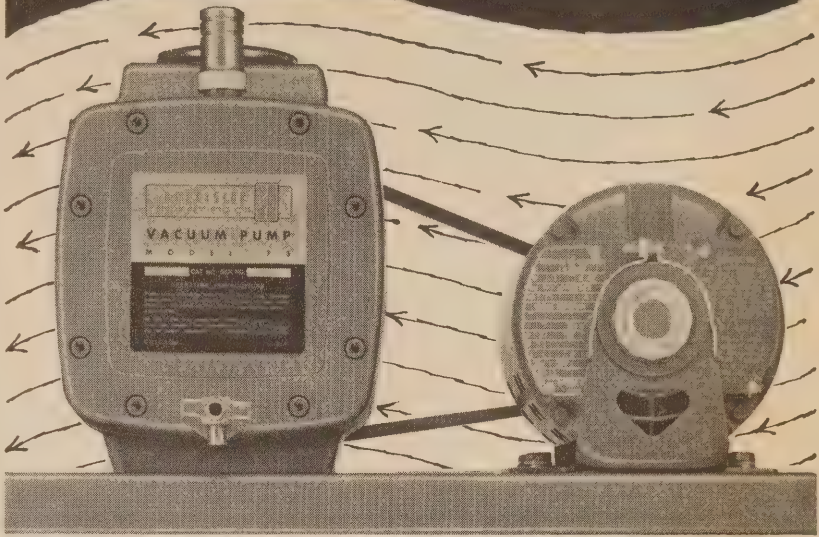
He joined IBM in the Research organization in June, 1951 as project engineer in charge of transistor research. In August 1952, he was appointed development engineer and continued working in transistor and semiconductor research. Following these assignments he advanced to other positions of greater responsibility and in December, 1958 was appointed resident manager of the Poughkeepsie Laboratory. During the year from October, 1957 through September, 1958 Dr. Hunter was on a sabbatical leave at the N. V. Philips Research Laboratories in Eindhoven, Netherlands, where he carried out personal research.

Before coming with IBM, Dr. Hunter taught physics at Carnegie Institute of Technology and solid state physics at the University of Pittsburgh. In 1942 he joined Westinghouse and worked in microwave magnetron development. Later, at the University of California, he worked on calutron development and in 1946, at the Oak Ridge National Laboratory, he conducted investigations of radiation effects in solids. In 1948 he rejoined Westinghouse as manager of the Solid State Electronics Section.

He received the B.A. degree in physics

(Continued on page 80A)

A complete line of new vacuum pumps that are quieter running, more efficient and designed to save space.



NEW PRECISION SCIENTIFIC VACUUM PUMPS

The Model 25
The Model 75
The Model 150

NOW — a complete new series of two stage, mechanical vacuum pumps designed and built with these features

GUARANTEED—Ultimate vacuum of 0.1 micron or better . . . all pumps are individually tested

MORE EFFICIENT—Pumps up to 33% more gas at pressures below 1 micron than any other pumps of similar rating

QUIET OPERATION—The only pumps using a cushioned exhaust valve . . . no disturbing clatter

LIGHTER AND SMALLER—Weigh ¼ less than pumps of similar capacity . . . require less space

MODERN DESIGN—Easier to clean and maintain . . . in keeping with today's modern laboratories

THREE SIZES—Free air capacities of 25, 75 and 150 liters per minute . . . sizes for most high vacuum needs

WIDE CHOICE—31 different types in all . . . variety of motor types including explosion proof . . . available with gas ballast, too.

Write today for Bulletin 610, Twelve pages of information including complete performance data

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IRE People

(Continued from page 79A)

at the College of Wooster, the B.S. degree in physics at the Massachusetts Institute of Technology, and the M.S. and D.Sc. degrees in physics from Carnegie Tech.

Dr. Hunter is a Fellow of the American Physical Society and a member of the American Institute of Physics and the New York Academy of Science. He is also a member of Phi Beta Kappa, Sigma Xi, Sigma Pi Sigma, Theta Chi Delta, and Phi Kappa Phi. He is an Associate Editor of the *Microwave Journal* and is a member of the Honorary Editorial Advisory Board of *The Solid State Electronics Journal.*

He has published a number of technical papers and holds ten patents and has several patents pending. He is the editor of "The Handbook of Semiconductor Electronics" which was published by the McGraw-Hill Book Company in 1956 and he is now editing the manuscript for the second edition of this book.

⁂

As part of a continually expanding engineering program, Zenith Radio Corporation has appointed **William S. Marks, Jr.,** (A'44–SM'44–F'52) as consultant in the military communications-electronics field.

Prior to association with Zenith, he was special assistant to the vice-president of the research division, Radiation, Inc., Orlando, Florida.

Previously, he spent many years with the U. S. Army Signal Corps, starting in 1930 as a junior radio engineer with the Signal Research and Development Laboratories, Fort Monmouth, N. J. He held various positions of increasing responsibility there, including chief of the vehicular radio section, chief of the radio communication branch, chief engineer and chief scientist of the Coles Signal Laboratory, and director of technical plans.

When the U. S. Army Electronic Proving Ground was activated at Fort Huachuca, Arizona, in 1954, he served as chief scientist and principal technical advisor to the installation's commanding general.

He pioneered in tank and other vehicular radio communications, and participated in the original radar experiments and developments at Fort Monmouth prior to World War II. He developed the radar transmitter which was used in the first successful demonstrations by the Army, and directed early experiments in the development of the Army's FM combat radios. In addition, he developed the first military radio relay system, for which he received the Legion of Merit.

In addition to his Civil Service career, he served with the Armed Forces as a radioman in World War I. During World War II, he served as a major and lieutenant colonel with the Signal Corps. He has been awarded the Army Commendation Medal with Oak Leaf Cluster.

Mr. Marks has a bachelor of science degree in electrical engineering from Louisiana State University, and has taken graduate work in physics at Union College, Schenectady, N. Y., and Rutgers University, New Brunswick, N. J. He is the author of a number of technical articles, and an inventor with several patents for inventions in the field of radio.

⁂

Goe Engineering has announced the appointment of **Milton Terkla** (A'55) as its new sales manager succeeding Jack Goergl.

His background since 1936 ncludes Sales Engineer of Aerovox Corp. and Litton, and Sales Manager of Alac Inc., and experimental engineering at Lockheed Aircraft.

⁂

Dr. Glen Wade (S'51–A'55–SM'57) has been named associate director of engineering—general research for the Microwave and Power Tube Division of Raytheon Company.

He had been associate professor of electrical engineering at Stanford University, Stanford, Calif., and a senior staff member of the Stanford Electronics Laboratories since 1955. He had also served as a consultant for Zenith Radio Corp., Philco Corp., and Diamond Ordnance Fuse Laboratory.

According to Bertram G. Ryland, divisional director of engineering, Dr. Wade will direct tube research in the areas of infrared, electron physics, microwave devices, and materials.

Holder of both the B.S. and M.S. degrees from the University of Utah, he received the Ph.D. degree from Stanford in 1954. He is a member of the American Physical Society, Phi Kappa Phi, Tau Beta Pi, Eta Kappa Nu and Sigma Xi, professional engineering societies.

He invented the quadrupole amplifier, a device for amplifying signals from distant bodies such as space vehicles, and has several other patents pending. He has had more than 20 technical papers published in the past five years.

Dr. Wade's offices will be located in Raytheon's Spencer Laboratory in Burlington, Mass., opened nine months ago for development of microwave tubes of all types.

⁂

Marion F. Thorne (A'54) has been appointed Assistant to Dr. Simon Ramo, Executive Vice President, Thompson Ramo Wooldridge Inc., according to an announcement by Dr. Ramo.

In his newly created post, he will continue to serve as Director of Executive Staff Services for the Ramo-Wooldridge Division.

He joined Ramo-Wooldridge in 1954 with fourteen years experience in administration and engineering. Prior to joining R-W he was with Thompson Products, Inc., Cleveland, Ohio, the firm that merged recently with Ramo-Wooldridge to form Thompson Ramo Wooldridge, Inc.

Mr. Thorne is a member of the Society of Automotive Engineers, Tau Beta Pi, Sigma Xi, and Omicron Delta Kappa. He is also a registered professional engineer in Ohio.

⁂

C. W. Slaybaugh (SM'51) has accepted the position of Director, International Enterprises, National Broadcasting Company, Inc. and will also serve as Vice Chairman of the Board, NBC International Ltd. He had been with RCA International Division since 1946, most recently as Manager, Special Marketing Development.

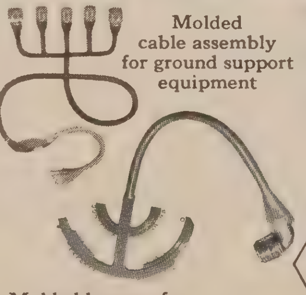
⁂

Dr. Herbert F. York, Director of Defense Research and Engineering, has announced that **Dr. Hector R. Skifter** (A'31–M'36–SM'43–F'51) has resigned as Assistant Director of Defense Research and Engineering (Air Defense). In 1957, he served the Department of Defense as a part-time consultant. In February, 1959, he took a leave of absence from his position as President of Airborne Instruments Laboratory to accept the full-time position of Assistant Director of Defense Research and Engineering. During his period of office, Dr. Skifter was responsible for technical evaluation and integration of defense weapons systems, planning and supervising the development of new and improved systems and their control en-

H. R. SKIFTER

(Continued on page 82A)

ROBERTSON MOLDED HARNESSES MEAN PROTECTION



Molded cable assembly for ground support equipment

Molded harness for underwater devices

against deterioration caused by acids, oils, fuels, flame, ozone, water or moisture.

against abrasion, shock, fungi, and temperature extremes.

Robertson molded cable assemblies have been painstakingly engineered and built to the same standards of military precision and dependability as the underwater devices, missile control systems, and mobile electronic equipment for which they are designed.

Robertson Electric Co., Inc.
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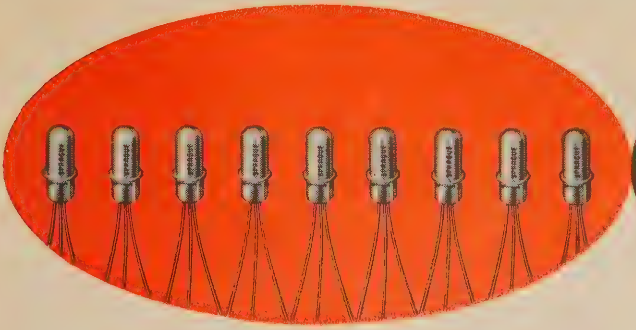
Established in 1895

new transistors from Sprague*



SUPER HIGH-SPEED SWITCHING TRANSISTORS TYPE 2N501

	Typical	Maximum	Units
Rise Time (t_r)	9	18	mμsec
Storage Time (t_s)	9	12	mμsec
Fall Time (t_f)	7	10	mμsec

In circuit with current gain of 10 and voltage turnoff.

Also available as special type 2N501A for 100° C. maximum storage and junction temperatures.

This table tells the story. Sprague Type 2N501 germanium micro-alloy diffused-base transistors are the fastest mass-produced transistors available anywhere! They are unexcelled for high-speed computer applications. The ultra-low rise, storage, and fall time cannot be matched by any other transistor.

Ultra-precise process control in manufacture results in superb and consistent high quality. The basic electrochemical process of fabrication takes the guesswork out of transistor manufacturing. The result is outstanding uniformity of product.

Because of the electrochemical process, Sprague is able to fabricate a graded-base transistor with no intrinsic base region. The Type 2N501 can thus maintain its super high-speed switching characteristics right down to its saturation voltage, providing all the advantages of direct-coupled circuitry with no impairment of switching speeds.

Type 2N501 Transistors are available from Sprague now at extremely reasonable prices. They are transistors you can use today! You need not delay your development work for the future when you design high-speed switching circuits with Type 2N501 Micro-Alloy Diffused-Base Transistors.

Write for complete engineering data sheet to the Technical Literature Section, Sprague Electric Company, 235 Marshall Street, North Adams, Massachusetts.

* *Sprague micro-alloy, micro-alloy diffused-base, and surface barrier transistors are fully licensed under Philco patents. All Sprague and Philco transistors having the same type numbers are manufactured to the same specifications and are fully interchangeable.*

SPRAGUE COMPONENTS:

TRANSISTORS • CAPACITORS • RESISTORS
MAGNETIC COMPONENTS • INTERFERENCE FILTERS
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Double Duty in Space

THE NEW Nems-Clarke 1906 AM/FM/CW Receiver has been reduced in height from 8⅜″ to 3½″ with no sacrifice of performance. With a tuning range of 30-260mc it gives more information while using less space. The 1906 Receiver has wide application in surveillance, countermeasures, direction finding and similar specialized military functions.

1906 RECEIVER

Tuning Range	30-260mc (two bands: 30-60mc, 60-260mc switched)
Noise Figure	6db maximum
Input Impedance	50 ohms unbalanced to Type N connector on rear apron
IF Rejection	65db minimum
Image Rejection	60db minimum
IF	21.4mc
IF Bandwidths:	300kc, 20kc (switchable from front panel)
Power Input:	115/230v AC, 50/60 cycles, 100w approx.
Size	19″ wide, 3½″ high, 15″ maximum depth

NEMS·CLARKE CO.

A DIVISION
OF VITRO
CORPORATION
OF AMERICA

919 JESUP-BLAIR DRIVE
SILVER SPRING
MARYLAND

PRECISION ELECTRONICS SINCE 1909

(Continued from page 80A)

vironment, including anti-aircraft and anti-missile missiles and interceptor aircraft.

As part of his duties he served as Chairman of the Ballistic Missile Defense Steering Group, spearheaded the installation of the BMEWS (Ballistic Missile Early Warning System) program, and coordinated the planning for the development of the NIKE-ZEUS and the ARPA DEFENDER programs. He served as a member of the Department of Defense Panel for the evaluation program of the BOMARC Weapon System and was the Chairman of the U. S. Delegation to the Tripartite Conference (United States, United Kingdom, and Canada) Technical Subgroup on Defense Against Ballistic Missiles.

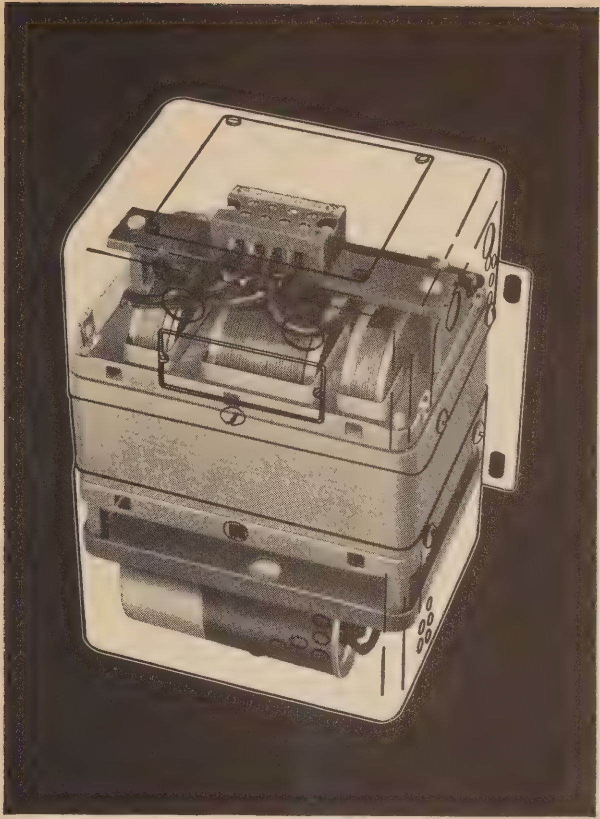
He is resuming his duties as President of Airborne Instruments Laboratory, a division of Cutler-Hammer, Deer Park, N. Y., and Vice-President and Member of the Board of Directors of Cutler-Hammer Inc.

Dr. Skifter was born in Austin, Minn. on March 4, 1901, and was graduated from St. Olaf College, Northfield, Minn., with the B.A. degree in 1922. In 1945 his alma mater awarded him an honorary D.Sc. degree. After graduation, he remained at the College until 1929 as an instructor in physics and mathematics. From 1929 to 1932 he was Chief Engineer of the Western Radio Company in Minnesota. From 1932 to 1942 he was a consulting radio engineer; from 1934 to 1942, he was technical supervisor of the National Battery Broadcasting Company. From 1942 to 1945 he was associate director of the Airborne Instruments Laboratory of the Columbia University Division of War Research under a contract with the Office of Scientific Research and Development (OSRD), responsible for the development of the airborne magnetometer for submarine detection and the development of electronic countermeasures against German guided missiles. In August, 1945, when the OSRD contract was terminated, Airborne Instruments Laboratory (AIL) was incorporated as an independent laboratory with Dr. Skifter as President. In June, 1958, AIL merged with Cutler-Hammer, Inc. He was elected to a vice-presidency of that corporation. In February, 1959, he was granted a leave of absence to serve as Assistant Director of Defense Research and Engineering.

Dr. Skifter has been a director of Cutler-Hammer, Inc. as well as of Intercontinental Electronics Corporation, and Cramer Controls, Inc., and was a member of the Gaither Security Resources Panel of the President's Science Advisory Committee. He is a member of the Cosmos Club, the Wings Club, and the University Clubs of Washington and Milwaukee. He is a director of Nassau Hospital, Long Island, New York; a trustee of Hofstra College; a director of the Long Island Fund; and a director of the Long Island Association.

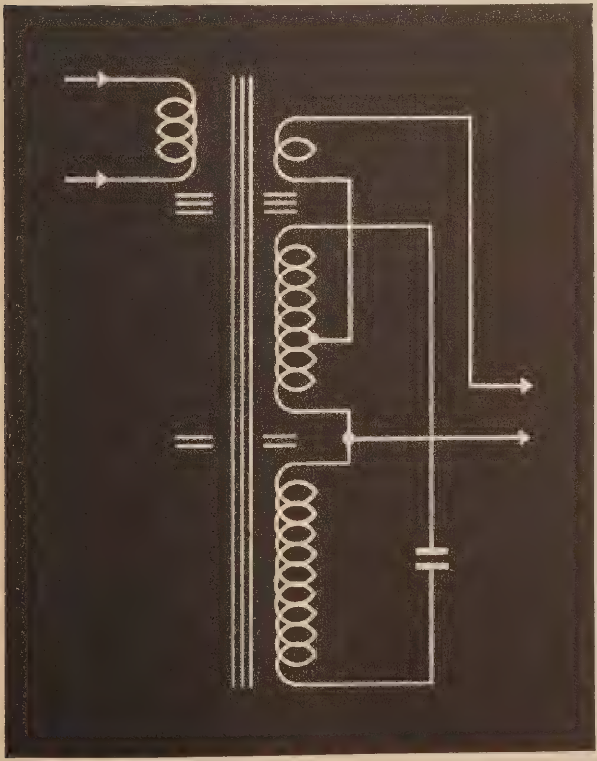
⁂

(Continued on page 84A)

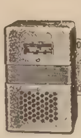


Phantom view shows simplicity of Sola design. Note absence of components requiring maintenance such as motors, gears, contactors, tubes and relays.

Schematic diagram indicates the complete reliance on static elements. This is the circuit of a representative Type CVS regulator which delivers output having less than 3% total rms harmonic content.



What's missing in this Sola voltage regulator?



When they designed the Sola Constant Voltage Transformer, what did they leave out? Trouble, for one thing. Original equipment manufacturers and plant engineers know that when you build in simplicity, you build out maintenance headaches.

The two illustrations at the left show clearly the Sola's few parts and straightforward design. This compact simplicity is possible because Sola regulators employ static-magnetic methods of voltage control.

The basic Sola design eliminates moving parts, renewable parts, manual adjustments, routine maintenance, and spare parts stock. Because there is nothing to wear out, no tubes to burn out — you know that when you specify Sola voltage stabilization, you automatically specify trouble-free reliability.

Despite this simplification, the Sola gives you these performance benefits: ±1% regulation over input voltage variations as great as ±15%, response time of 1.5 cycles or less, protection against short circuits for itself and its load, a high degree of isolation between input and output circuits, and negligible external field. Type CVS (illustrated with typical circuit diagram) delivers a commercial sine wave with less than 3% total rms harmonic content.

Sola static-magnetic units are available for regulation of common line voltages, as well as filament, plate-filament, computer-circuit and variable voltage outputs. They can also be supplied in step-up and step-down ratios to replace conventional non-regulating transformers.

Whether you are developing new electric or electronic equipment, or have a specific voltage regulation problem, your nearest Sola sales engineer will be happy to discuss your requirements with you.

Write for Bulletin 1F-CV

SOLA

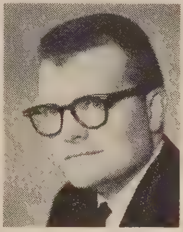
B P C

SOLA ELECTRIC CO. A Division of Basic Products Corporation
4633 West 16th Street Chicago 50, Illinois

IRE People

(Continued from page 82A)

Homer R. Denius, President of Radiation Inc., announced the appointment of **Richard M. Hultberg** (S'49–A'51–M'57) as Director of the Systems Development Division—Melbourne, Fla.



R. M. Hultberg

Prior to joining Radiation, Mr. Hultberg had been with the International Telephone and Telegraph Corporation for ten years. While there, he held the positions of Manager, Electronic Products Division of ITT's Kellogg Division, Director of ITT Laboratories and Technical Assistant to the Executive Vice President, U. S. Group Companies, ITT.

Under his direction, many communications and electronic systems used by the military have been developed and manufactured. His experience includes direction of research, development and industrial manufacturing operations. His most recent assignment was ITT Deputy Director for UNICOM, a joint world-wide communications project being carried out by Bell Telephone Laboratories, ITT and RCA for the Signal Corps.

Mr. Hultberg is a member of the American Institute of Electrical Engineers and the American Management Association.

❖

Dr. John T. Ludwig (S'47–A'55), until recently a senior research and development engineer with Minneapolis-Honeywell Regulator Company, has been appointed to Scientific Advisory Group of Electronic Communications, Inc. as a principal engineering scientist.

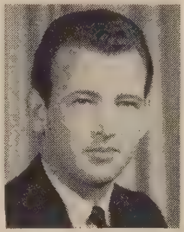
With Honeywell from 1954 to 1960, he was responsible for electrical engineering research at the corporate research center. His personal research projects were in the fields of magnetic circuits, electrostatic motors, liquid-metal gyroscopes, and magnetic and electric support of gyroscopes.

Dr. Ludwig received the B.S., M.S. and Ph.D. degrees at the University of Minnesota. As a University Research Fellow he designed electronic instrumentation for solid state and vacuum tube research, investigated design methods for electrical inductors, and designed electronic apparatus for the linear proton accelerator. While with the Minnesota Mining and Manufacturing Company in 1951, he was engaged in the study of the magnetic tape recording of high frequency (television) signals.

Dr. Ludwig is a registered professional engineer in Minnesota, and a number of AIEE, and NSPE. He serves on NSPE committees on engineers in industry and on engineering technicians, is the author of several technical and nontechnical articles, and has recently completed three articles for AIEE *Transactions.*

❖

It was announced by Microlab that **Harry C. Dolan** (A'59) has been appointed Sales Manager at Microlab, a manufacturer of microwave coaxial components.



H. C. Dolan

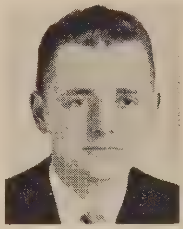
His responsibilities include developing a national field sales organization and over-all sales administration. He will assist in commercial planning, administration, advertising and sales promotion.

He is a graduate of Seton Hall University, where he received the B.S. degree in 1949. He is a member of the Armed Forces Communications and Electronics Association.

Prior to joining Microlab, Mr. Dolan was employed by Frequency Standards, Asbury Park, as Sales Manager.

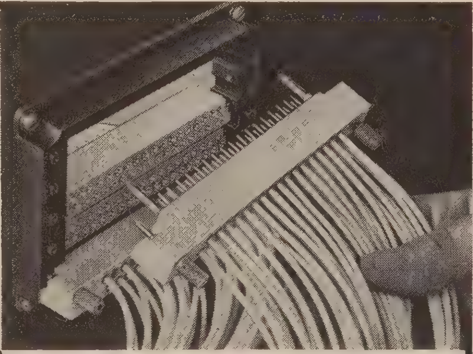
❖

Edwin O. Brown (M'57) has been named Philadelphia district manager for the Weston Instruments Division of Daystrom, Incorporated.



E. O. Brown

He received a B.S. degree in electrical engineering from Tufts University in 1948. He joined Weston in 1957 and a year later was appointed manager of the Syracuse Office. He is a senior member of the Instrument Society of America.



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Makes possible the design of lighter and more compact equipment. Each insert holds 35 contacts. Frames available for 5 or 8 inserts.

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Professional Group Meetings

AERONAUTICAL AND NAVIGATIONAL ELECTRONICS

Dayton—November 5

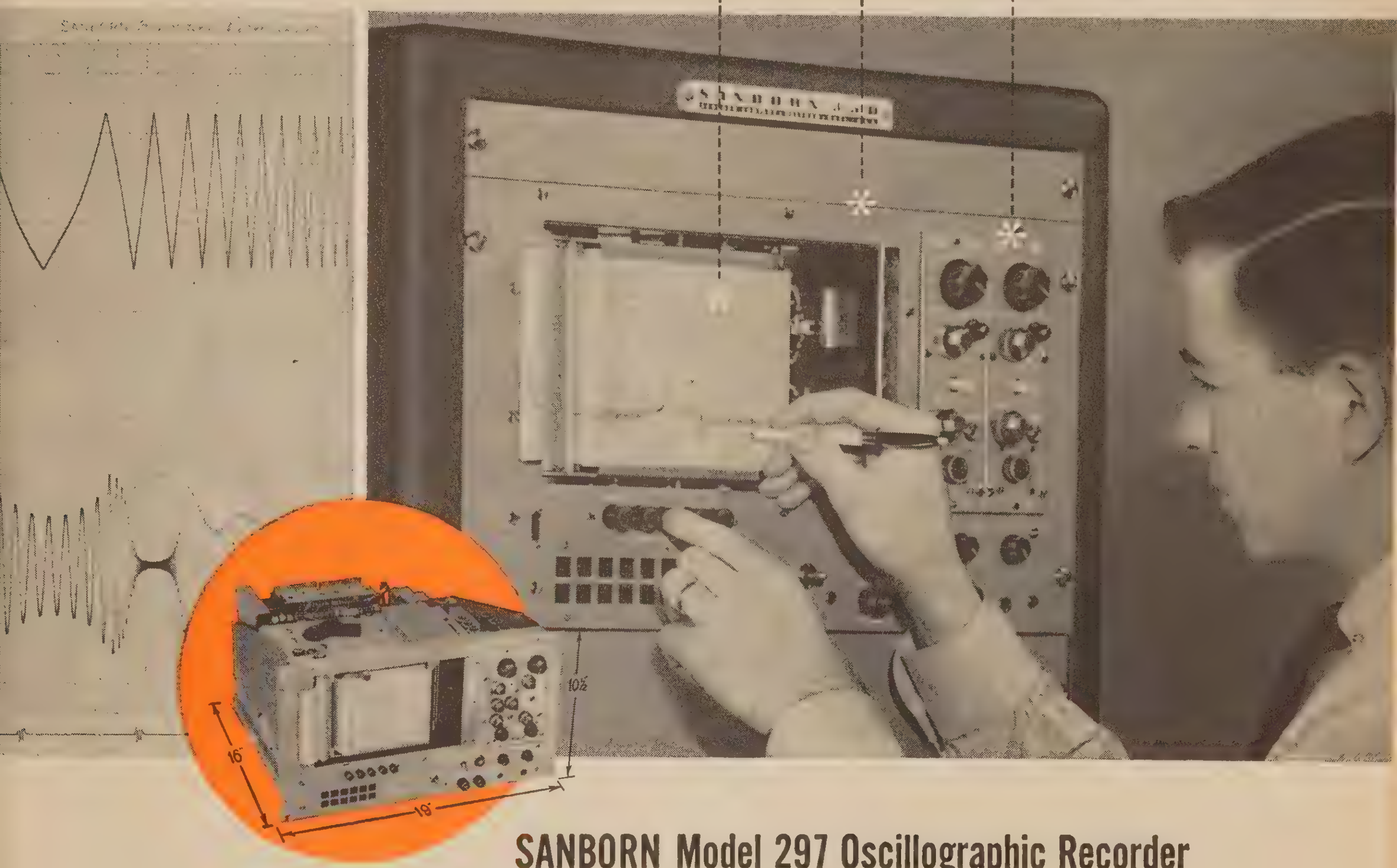
"On the Detection of Earth Satellites by Means of Radio Reflections," T. G. Hame, Ohio State Univ. Res. Foundation.

Oklahoma City—February 23

"A New Transistorized Commercial Airborne Weather Radar," J. F. Beckerich, Collins Radio Co., Dallas, Texas.

(Continued on page 86A)

THIS NEW 2-CHANNEL DIRECT WRITER...



has easily read 50 mm wide, rectangular coordinate channels

mounts in 10½" of rack space or in a separate portable case

interchangeable "850" Series plug-in preamplifiers for each channel

SANBORN Model 297 Oscillographic Recorder

Compactness and versatility without loss in performance is the design concept for this new 2-Channel Direct-Writer from Sanborn. The Model 297 provides two *complete* recording channels in only 10½" of panel space, making it extremely useful as a monitoring recorder — integrated with large instrumentation setups in data processing installations, test stands and similar applications. In its own portable case, the Model 297 will be equally useful in *laboratories and field applications* as a bench-top instrument.

Preamplifiers are "850" Series plug-in interchangeable units, available in Carrier, DC Coupling, Phase Sensitive Demodulator, and Low Level types. They may be used in any combination, one for each channel. An internal MOPA for carrier and chopper excitation is also available.

The basic recorder assembly houses a preamplifier power supply, transistorized power-amplifier power supply, and two transistorized current-feedback power amplifiers with *built-in electrical limiters* that provide damping at all times. The entire unit has built-in forced filtered air cooling.

The recording mechanism has rugged, enclosed galvanometers with velocity feedback damping . . . 4 different chart speeds selected by push buttons . . . timer/marker stylus with 1 second timer . . . approximately 6 inches of visible chart with immediately visible traces made by heated stylus. The electrical and mechanical specifications in combination with the many "big system" operating features make the compact Model 297 one of the most useful, reliable 2-channel direct writers available.

Contact the Sanborn Sales-Engineering representative nearest you or write the main office in Waltham for complete information and application assistance. Sales-Engineering representatives are located in principal cities throughout the United States, Canada and foreign countries.

Model 297 2-Channel Recording System Specifications
(Less plug-in preamps)

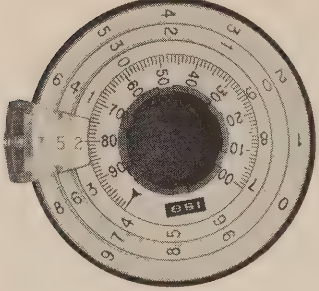
Sensitivity: 0.1 volt/mm nominal
Frequency Response: DC to 125 cps within 3 db, 10 mm peak-to-peak amplitude
Gain Stability: Better than ½% from 20°C to 40°C or line voltage change from 103 to 127 volts
Linearity: Max. non-linearity is 0.2 mm
Electrical Limiting: Approximately ±115% of full scale
Chart Speeds: 1, 5, 20, and 100 mm/sec. by mechanical push button
Dimensions: 10½" high x 16" deep x 19" wide
Paper Take-up: electrically operated

(Specifications are subject to change without notice.)

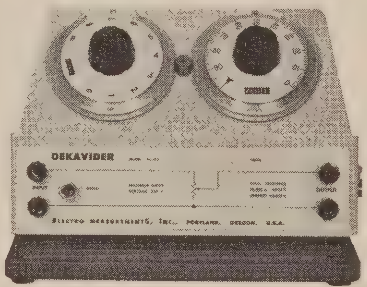
SANBORN COMPANY
Industrial Division
175 Wyman Street Waltham 54, Massachusetts

esi VOLTAGE DIVIDERS

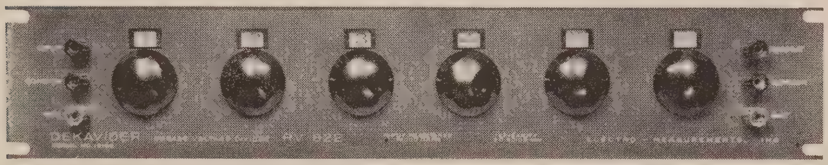
linearity to 10 ppm



PANEL MOUNT DEKAPOTS®
Linearity to 50 ppm. Resolution to 0.0003%. Three or four decades (with 100 Div. Pot.). Available in standard resistance values of 1K, 10K and 100K. Order from stock. Price—$95 to $175.



BASE MOUNT DEKAVIDERS®
Linearity to 50 ppm. Resolution to 0.0003%. Three decades (plus 100 Div. Pot.) and four decades Available in standard resistance values of 10K and 100K. Order from stock. Price—$145 to $160.



RACK MOUNT DEKAVIDER®—**Precision resistors closely matched for maximum accuracy. Linearity—10 ppm. Resolution—0.0001%. Standard resistance value—10K. 30-day delivery. Price—$450.**

PRECISION DECADE RESISTIVE VOLTAGE DIVIDERS providing known voltage and current ratios for meter calibration, linearity checking, ratio measuring, synchro testing, computer standardization, many other applications requiring the high resolution and accuracy of the Kelvin-Varley circuit. In-line control knob on the rack-mounted divider and the exclusive ESI DEKADIAL® coaxial dial of the other units simplify dial settings, permit easy in-line readings. Low reactance design of the precision mica card resistors and minimum capacitance arrangement of the circuits provide audio frequency performance comparable to high dc accuracy. Non-standard resistance values available on special order.

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(Continued from page 84A)

ANTENNAS AND PROPAGATION

Akron—February 23

"Artificial Earth Satellites and the Ionosphere," T. G. Hame, Ohio State Univ. Antenna Lab.

Los Angeles—February 24

"Conical Helix Feed for Parabolic Antenna" Dr. R. Yang, Andrew Corp.

Los Angeles—March 10

"The Randome—Science or Crystal Ball," F. M. Millican, Convair, San Diego, Calif.

San Francisco—January 13

"New Ideas in High Frequency Antenna Design," R. Tanner, Stanford Res. Inst.

San Francisco—April 6

"Introduction to Radio Astronomy," R. N. Bracewell, Stanford Univ.

AUDIO

Milwaukee—March 15

"Current Aspects of Stereo Record Reproduction," R. Anderson and R. Carr, Shure Bros, Evanston, Ill.

San Francisco—March 1

"Why Stereo," J. McKnight, Ampex Corp.

Syracuse—February 9

"Psychoacoustical Aspects of Sound," R. L. Hanson, BTL.

AUTOMATIC CONTROL

Dallas-Fort Worth—March 7

"A Control System for a Missile with a Swivelable Solid Rocket Motor," L. L. Meyer, Chance Vought Aircraft, Inc.

Los Angeles—November 10

"Adaptive Flight Control Systems," L. Prince, Minneapolis-Honeywell Co.

Los Angeles—December 8

"Aircraft Flight Control Systems," R. K. Smyth and E. R. Buxton, North American Autonetics.

Los Angeles—January 21

"Variational Calculus Principles Applied to Adaptive Flight Control Systems," R. Barron, DODCO.

Los Angeles—February 9

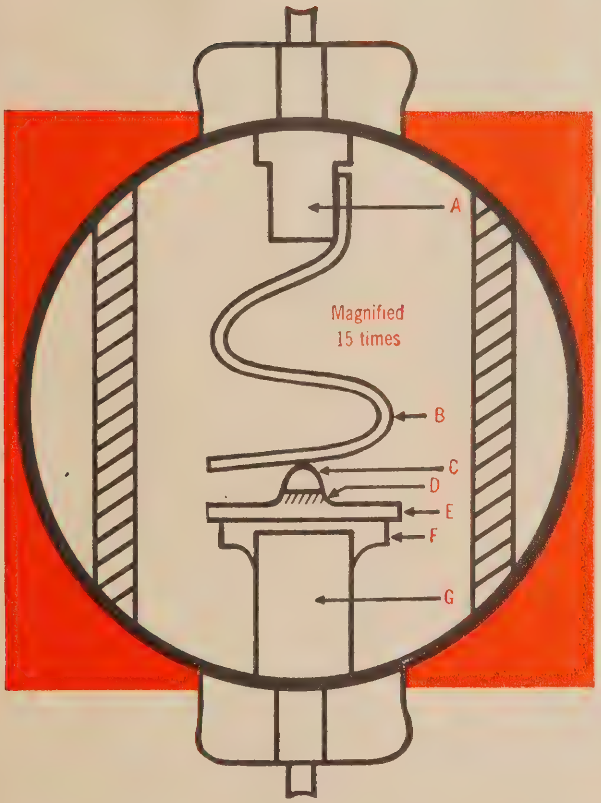
"Adaptive Automatic Flight Control System," K. C. Kramer, Lear, Inc.

Los Angeles—March 8

"Adaptive Control Systems," R. M. Du Plessis, North American Autonetics.

(Continued on page 88A)

announcing reliable diffused silicon diodes



A – dumet, B – platinum, C – gold, D – diffused region, E – N-type silicon, F – gold, G – dumet.

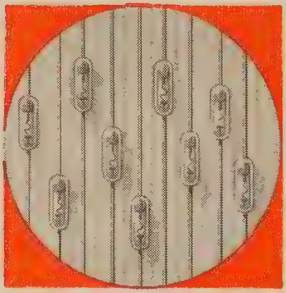
Active portion and consequently the capacitance of these diodes are minimized by etching away all but a small diffused section. Rugged construction provides resistance to shock and vibration exceeding MIL-STD. 202A.

More reliable products through Advanced Engineering

Advance-engineered diffusion techniques are now applied to CBS silicon diodes. Fast switching . . . high conductance . . . high temperatures . . . high voltage . . . low capacitance . . . and low reverse current are achieved.

The diffusion technique offers many other advantages over the alloying method: Close process control of all parameters, great uniformity, and high reverse voltage for a given resistivity through the graded junction. Hermetic sealing of miniature glass package also contributes to the exceptional life.

Now you can have proven CBS reliability in diffused silicon diodes. Watch for further announcements on this growing CBS silicon line.



a comprehensive line
for computers

Note the two major classifications particularly designed for computers in missiles, rockets, airborne and industrial equipment. Typical applications include switching, pulse, flip-flop, modulator, demodulator, discriminator, clamping, gating and detector circuits. Write for complete technical Bulletins E-373 and E-374.

FAST RECOVERY TYPES

Type	Min. Rev. Voltage @ 100 μA (volts)	Min. Forward Current		Maximum Reverse Current				Reverse Recovery Characteristics*	
				@ 25°C		@ 100°C			
		I_F (mA)	E_F (volts)	I_R (μA)	E_R (volts)	I_R (μA)	E_R (volts)	Zrec (Kohms)	t (μsec)
1N625	–35	4	1.5	1	–20	30	–20	400	1.0
1N626	–50	4	1.5	1	–35	30	–35	400	1.0
1N627	–100	4	1.5	1	–75	30	–75	400	1.0
1N628	–150	4	1.5	1	–125	30	–125	400	1.0
1N629	–200	4	1.5	1	–175	30	–175	400	1.0

*JEDEC 14.5-1 (Modified IBM-Y reverse recovery circuit with:
$I_F = 30$mA, $E_R = -35$V, $R_L = 2$K ohms.)

HIGH CONDUCTANCE TYPES

Type	Min. Rev. Voltage @ 100 μA (volts)	Max. Fwd. Voltage @ 100 mA (volts)	Maximum Reverse Current				Max. Avg. Fwd. Current	
			@ 25°C		@ 150°C			
			I_R (μA)	E_R (volts)	I_R (μA)	E_R (volts)	@ 25°C (mA)	@ 150°C (mA)
1N482	–40	1.1	0.25	–30	30	–30	100	25
1N483	–80	1.1	0.25	–60	30	–60	100	25
1N484	–150	1.1	0.25	–125	30	–125	100	25
1N485	–200	1.1	0.25	–175	30	–175	100	25

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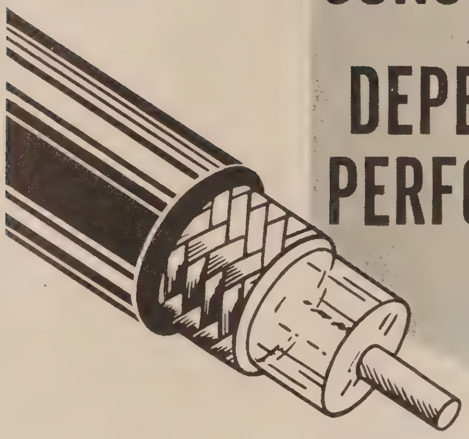

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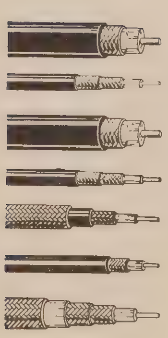

Army-Navy Type No.	Dia. of Dielectric In.	Nom. IMP. OHMS	Attenuation DB/100 ft. 400 Mc	3000	Shielding Braid	Nom. Overall Dia. In.
RG-8A/U	.285″	52	6	19	Single Copper	.405
RG-9B/U	.280″	50	6.1	21.8	Double Copper	.420
RG-11A/U	.285″	75	5.2	18.5	Single Copper	.405
RG-13A/U	.280″	75	5.7		Double Copper	.420
RG-17A/U	.680″	52	2.8	11	Single Copper	.870
RG-59A/U	.146″	75	9	30	Single Copper	.242
RG-74A/U	.370″	50	4.3	14	Double Copper	.615

All Hickory Brand Electronic Wires and Cables are quality-engineered and precision-manufactured to meet the exacting requirements of the industry.

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Professional Group Meetings

(Continued from page 86A)

BIO-MEDICAL ELECTRONICS

Montreal—February 29

"Electronics—Its Effect on Physiological Teachings and Research," C. Pinsky, G. Mandl, G. Smith, Physiological Res. McGill University, Montreal, P. Q.

Portland—November 28

Organizational meeting.

Portland—February 11

Election meeting.

Portland—March 10

Series of papers on "Engineer's Night at Medical School," Mr. Frederick, Dr. R. Thompson, Dr. J. Roth, Dr. G. Austin, Dr. B. Ross and Dr. A. Starr, Medical School, Portland, Ore.

BROADCASTING

Cleveland—March 10

"Automatic Logging of Critical Transmitter Parameters," R. H. Woods, Brown Instruments Div., Minneapolis-Honeywell Reg. Co., Cleveland, Ohio.

Florida West Coast—March 16

"Radio Frequency Measurements and Interference Prediction Techniques," D. White, Frederick Research Corp., Bethesda, Md.

Omaha-Lincoln—March 24

"First Open House, New 9 Story Addition, Lincoln Tel. and Tel. Building," R. Ghormley, Lincoln Tel. & Tel. Co., Lincoln, Neb.

Philadelphia—February 18

"A Cartridge Tape System for Broadcasting," H. Hepler, Collins Corp.

Vancouver—January 18

"The Operational Aspects of Color Television," R. Mifflin, Television Station KOMO-TV, Seattle, Wash.

CIRCUIT THEORY

Syracuse—March 29

"An Aspect of Feedback Theory, and its Application to Transistor Circuits," J. H. Mulligan, Jr., New York Univ.

COMMUNICATIONS SYSTEMS

Omaha-Lincoln—December 11

"Antarctica, Propagation, and the National Bureau of Standards," F. W. Brown, NBS.

Omaha-Lincoln—March 30

"Bell Boy Signaling," A. A. Little, Northwestern Bell Tel. Co.

Philadelphia—March 29

"An Automatic Air Traffic Control System," A. W. Muoio, RCA.

San Francisco—January 27

"Propagation Factors in the Design of Scatter Circuits," W. H. Kummer, Hughes Aircraft Co.

San Francisco—February, 24

"Department of Defense: Problems, Policies and Objectives in World Wide Communications," R. Clark, Dept. of Def. Res. and Eng.

Syracuse—December 10

"Venus Radar Experiment," W. B. Smith, M.I.T., Lincoln Lab.

COMPONENT PART

Baltimore—February 16

"Recent Developments in the Sub-Miniature Relay Field," L. DeLalio, Filtors, Inc., Port Washington, N. Y.

ELECTRON DEVICES

Los Angeles—March 24

"A New Class of Solid State Traveling Wave Parametric Amplifiers for Microwaves," Dr. M. R. Currie, Hughes Aircraft Co.

San Francisco—December 2

"Microwave Generation Using Ferrites," H. J. Shaw, Stanford Univ.

San Francisco—January 27

"Thermionic Cathodes: The State of the Art," L. Cronin, Semicon Corp.

San Francisco—February 29

"Crossed Field vs Linear Beam in Microwave Super-Power Generation," W. C. Brown, Raytheon Corp.

San Francisco—March 28

"Solid State Micrologic Elements," R. Norman, Fairchild Semiconductor Corp.

ELECTRONIC COMPUTERS

Boston—December 8

"Computer Study of the Nervous System," W. Clark, Lincoln Lab.

Boston—March 23

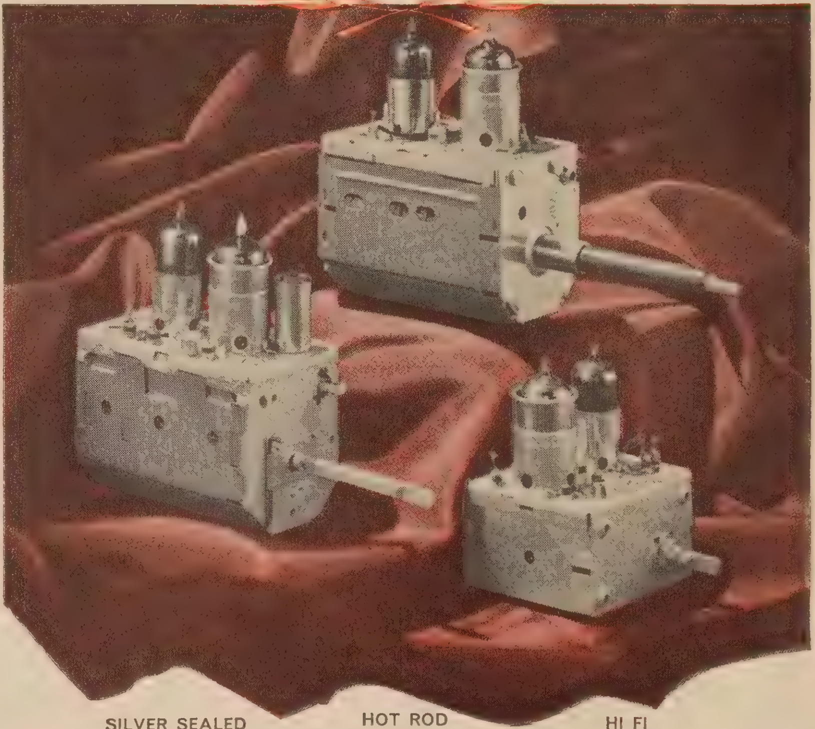
"Electronic Business Data Processing—Its Cause and Cure" Charles W. Adams, Chas. W. Adams Associates, Inc.

Los Angeles—March 17

"The RW400—A Polymorphic Computer," E. Bolles and S. Rothman, Ramo-Wooldridge Corp.

(Continued on page 90A)

The World's
FINEST TUNERS
For the World's
FINEST SETS



SILVER SEALED (switch-type) HOT ROD (turret-type) HI FI (FM) Tuner

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Today, only Tarzian offers manufacturers both the HOT ROD (turret-type) and SILVER SEALED (switch-type) . . . as well as the newer Hi Fi FM Tuner. All with built-in HIGH-QUALITY . . . DEPENDABILITY . . . UNEXCELLED PERFORMANCE . . . at low cost!

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Tuner Division

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Manufacturers of Semiconductors, Air Trimmers and Broadcast Equipment

Professional Group Meetings

(*Continued from page 89A*)

Philadelphia—October 6

"The Design of More Intelligent Machines," H. J. Gray, Moore School of Electrical Engineering, Univ. of Pa.

Philadelphia—December 8

"What Automatic Programming of Computers Means to Engineers," G. Hopper, Remington Rand, Univac Div.

Philadelphia—February 9

"Solid State Electronics in the Burroughs Check Sorter," T. Dowds and H. Rosenberg, Burroughs Res. Center.

Philadelphia—March 15

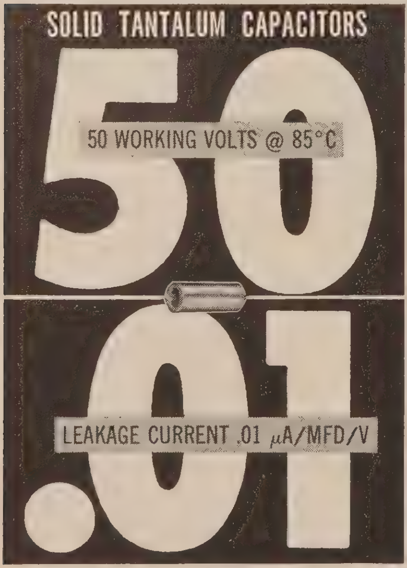
"Military Field use of Digital Systems and Human Factors Considerations," W. F. Luebbert, U. S. A. Signal Corp.

Pittsburgh—February 2

"Analogue to Digital Conversion," R. Knapp, Rensselaer Polytechnic Inst.

San Francisco—February 23

"The Role of the University in the Computer Sciences," Dr. L. Fein, Consultant, Palo Alto, Calif.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ENGINEERING MANAGEMENT

Boston—February 18

"Human Factors in Group Productivity," Dr. F. L. W. Richardson, Business Consultant.

Dayton—November 18

"The Role of the AMC Commodity Depots in Electronic Subsystems and Component Logistics," C. E. Jung, Dayton Air Force Depot.

Syracuse—March 10

"Concepts for Effective Leadership of Engineering Organizations," T. S. Lisberger, Cornell Univ., School of Industrial and Labor Relations.

ENGINEERING WRITING AND SPEECH

Boston—April 6

"The Place of English in the Engineering Curriculum,"R. T. Kendall, Communications and Data Processing, Raytheon Co.

Los Angeles—January 20

"Communications in Science and Industry," J. Bennett, Systems Development Corp., Santa Monica, Calif.

Washington, D. C.—March 7

"How to Capture a Technical Audience," D. C. S. Daniel, Attorney-at-law, Washington, D. C. and Capt. O. Gregg, USN Ret., Tecnifax Corp.

INFORMATION THEORY

Los Angeles—February 23

Panel Discussion on "The Application of Information Theory to Communication System Design," Dr. L. Zadih, Univ. of California, Berkeley, Dr. E. Rechtin, Calif. Inst. of Tech., Dr. G. Turin, Hughes Aircraft and Dr. S. Lutz, Hughes Aircraft.

INSTRUMENTATION

Los Angeles—October 7

"Zero Space, Negative Weight and No Power Consumption for Airborne Data Recording," E. D. Lucas, Jr., Leach Corp.
"Instrument for Automatic Testing," N. Marshal, Leach Corp.

Washington—February 15

"Project Score (a satellite communication system)," S. P. Brown, U. S. Army Signal Res. Lab.

MEDICAL ELECTRONICS

Los Angeles—March 17

"Methods of Measuring Cerebral Blood-Flow," W. Oldendorf, Veterans Administration Center.

MICROWAVE THEORY AND TECHNIQUES

Chicago—September 11

"Logarithmic Periodic Antennas," R. H. DuHamel, Collins Radio Co.

Los Angeles—February 11

"Present State of the Microwave Computer Art," B. Havens and G. Bland, IBM.

San Francisco—February 9

"Principles of Traveling Wave Antennas," A. A. Oliner, Microwave Res. Inst.

Washington—February 9

"Millimeter Waves: The Transmission Problem," Dr. D. C. Hogg, Bell Telephone Labs, Holmdel, N. J.

Washington—February 23

"Millimeter Wave Sources and Detectors," Dr. W. R. Beam, Rensselaer Polytechnic Inst., Troy, N. Y.

Washington—March 8

"Millimeter Components, Special Devices, and Techniques in Waveguides," Dr. S. Hopfer, Polytechnic Res. & Dev. Corp., Brooklyn, N. Y.

MICROWAVE THEORY AND TECHNIQUES
ANTENNAS AND PROPAGATION

Columbus—March 14

"The Ionosphere—Frontier of Space," S. A. Bowhill, Pennsylvania State Univ.

San Diego—February 8

"The Technical Aspects of Radiation Hazards," W. W. Mumford, Bell Telephone Labs, Whippany, N. J.

Syracuse—February 23

"A Brief Trip Report on Microwave Engineering in Japan" Dr. K. Tomiyasu, General Electric Co., Palo Alto, Calif.

MILITARY ELECTRONICS

Boston—March 31

"Military Reliability and Quality Control Requirements," P. K. McElroy, General Radio Co.

Dayton—October 22

"Weapon Systems Management," J. R. Holzapple, Commander, ARDC Directorate of Systems MGT.

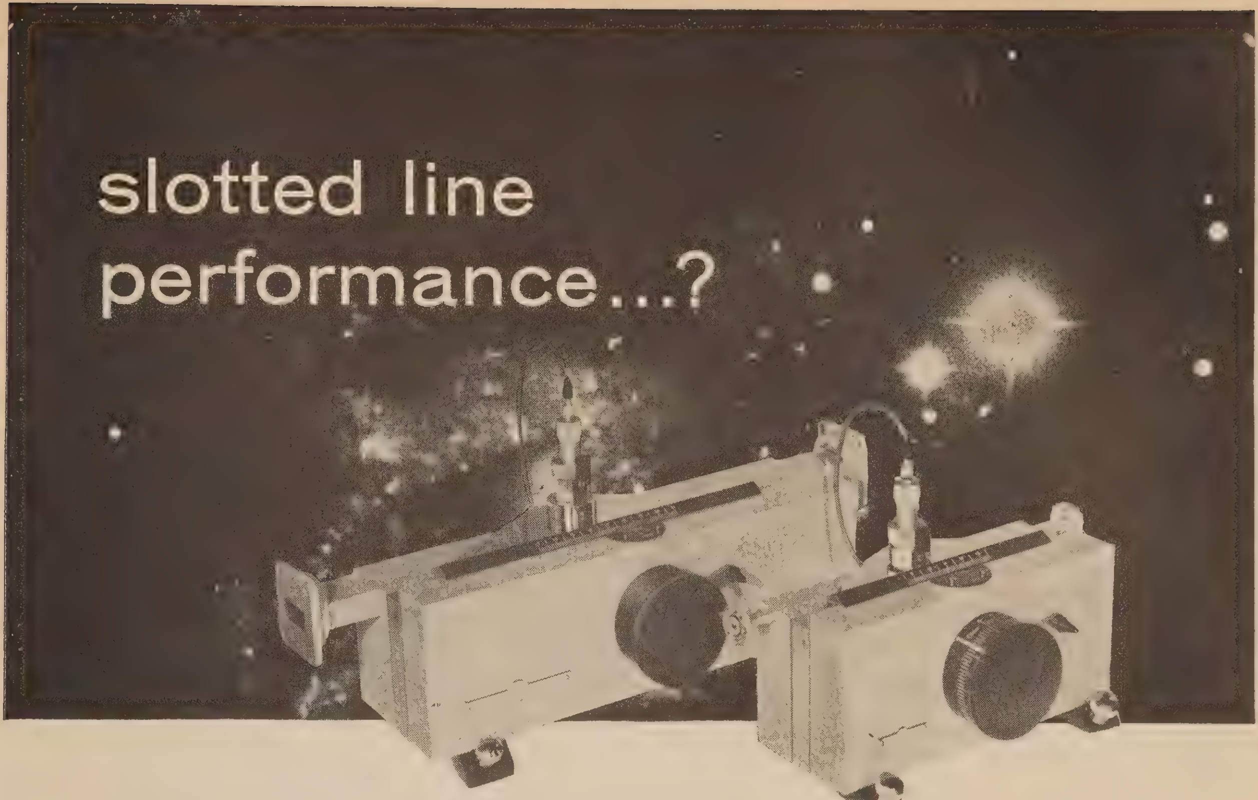
Dayton—December 3

"Speech Bandwidth Compression," K. Otten, Communications & Nav. Lab., WADD.

Indianapolis—February 25

"Power Transmission Without Wires Using Microwaves," Dr. R. L. McFarlan, President IRE.

(*Continued on page 92A*)



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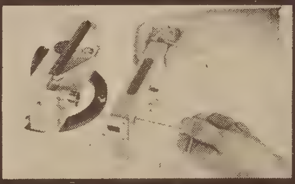

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waveguide blocks.
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perfectly to
probe travel
in a few seconds.

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Professional Group Meetings

(Continued from page 90A)

Los Angeles—September 23

"Air Force Ballistic Missile Training Program," A. R. Sult, USAF.

Los Angeles—November 24

Paper and Panel Discussion: "The Economic Challenge to the Military Systems Engineer," F. S. Pardee; Panel Moderator: F. G. Suffield; Panel Members: T. W. Johnson, W. E. Sweeney, USN, R. S. Isensen, Lt. Col. USA, S. Greene, Lt. Col. USA.

Philadelphia—February 17

"Communications in High Intensity Noise," W. F. Meeker, RCA.

NUCLEAR SCIENCE

Connecticut—September 30

"Review of Radiation Particles and Gas Monitors," C. Bycoski, Combustion Engineering, Inc.

Connecticut—November 4

"Data Collection and Processing with Magnetic Tape Punched Cards," S. Oakleaf, Combustion Engineering Inc.

Oak Ridge—March 17

"The Oak Ridge Isochromous Cyclotron," J. R. Jones, Union Carbide Nuclear Co.

PRODUCTION TECHNIQUES

Boston—March 8

"Panel Discussion—Small Business," D. Buell, Small Bus. Adviser; P. Wilson, Raytheon; C. Kelly, General Radio; C. H. Wells, Foxboro Co.

Los Angeles—January 21

"Electronics Packaging—Space Satellites," A. Geduld and R. Danta, Space Technology Labs.

Los Angeles—March 31

"Wave Solder Techniques in Printed Circuit Production," R. Marks, Robert Marks Associates.

Philadelphia—February 22

"Scope and Objectives of Naval Human Engineering Research," L. Guerino U. S. Navy.

"Space Astronaut Program," K. R. Coburn, U. S. Navy.

RADIO FREQUENCY INTERFERENCE

Fort Worth—April 12

"Initial Interference Testing of the B-58 Aircraft" S. T. Collie, Convair.

Washington—October 20

"A History of Interference Problems of the FCC," G. S. Turner, FCC.

Washington—December 15

"Advanced Technology and Future Problems in Radio Frequency Interference," G. P. Sutton, Advanced Research Projects Agency.

Washington—February 1

"How Are We Conserving Our Natural Resources—The Radio Spectrum," Commodore E. W. Webster, Moderator (Consultant, Kensington, Md.).

Washington—February 15

"Project SCORE," S. P. Brown, U. S. Army Signal Res. Lab., Fort Monmouth, N. J.

RELIABILITY AND QUALITY CONTROL

Boston—February 25

"System Reliability," W. T. Sumerlin, Philco Corp.

Boston—March 31

Joint Meeting on Military Reliability and Quality Control Requirements.

Philadelphia—November 17

"The Specification of Component Part Reliability," D. Troxel, RCA.

Philadelphia—February 2

"System Optimization, for Least Cost of Redundancy," J. D. Kettelle, Jr., Kettelle and Wagner Consultants.

"Reliability Models," P. R. Gyllenhall, RCA.

Philadelphia—March 8

"Reliability Prediction," H. L. Wuerffel, RCA.

"Pros and Cons for the Use of a Controlled Environmental Laboratory," Karl Zimmer, Burroughs.

"Worst-Case Versus Statistical Design," J. Jamison, Philco Computer Div.

San Francisco—February 2

"Construction of Microminiature Photocells," C. Reise, Hewlett-Packard.

San Francisco—February 23

"Microminiaturization Work at Lockheed," W. D. Fuller, Lockheed Missile and Space Div.

VEHICULAR COMMUNICATIONS

Detroit—February 24

"Getting the Best Out of Your Two Way System," W. Wray, Motorola, Inc.

Detroit—March 30

"15KC Splits—A new source of channels in the 150mc band," J. McCormick, GE Co.

Florida West Coast—February 8

"What IRE is doing for YOU," R. L. McFarlan, Pres. of IRE.

Los Angeles—February 18

"Effective Sensing of VHF Receivers as Limited by Noise-Xmtr. Radiation and Antenna Replacement," J. M. Eakin, Motorola, Inc.

Los Angeles—March 17

"Fact and Fancy of Antenna Gain Measurements," J. D. Cupp, Andrew Calif. Corp.

Philadelphia—March 29

"An Automatic Air Control System," A. W. Muoio, RCA.

Membership

The following transfers and admissions have been approved and are now effective:

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Bloemsma, J., The Hague, Netherlands
Frye, E. O., Marion, Iowa
Jones, E. M., Cincinnati, Ohio
Mendelson, D. A., Akron, Ohio
Norman, J. E., Huntsville, Ala.
Peters, L., Jr., Columbus, Ohio
Pinnell, J. E., Lachine, Que., Canada
Richardson, R. M., Sterling, Va.
Ross, G. F., Plainview, L. I., N. Y.
Segel, D. L., Los Angeles, Calif.
Shafer, M. W., Severna Park, Md.
Shem, I., Eau Gallie, Fla.
Steiger, W., Newport Beach, Calif.
Strain, D. C., Portland, Ore.
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Welch, D. P., Buffalo, N. Y.
Wittenberg, W. M., Poughkeepsie, N. Y.

Admission to Senior Member

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Clynes, M. E., Orangeburg, N. Y.
Esaki, L., Poughkeepsie, N. Y.
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(Continued on page 94A)

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FOR COMPUTER APPLICATIONS

2N695	World's fastest-switching transistor. TO-17 package with 4th lead for high frequency shielding. High-speed performance such as 50mc flip-flops.
2N705	Combines same high-speed switching as 2N695 with 300mw device dissipation. TO-18 package.
2N710	Lower cost Motorola Mesa switch for less critical switching applications. TO-18 package with 300mw device dissipation.

FOR UHF-VHF AMPLIFIER APPLICATIONS

2N700	For 40 to 1000mc communications applications. TO-17 package with fourth lead providing high frequency shielding.
2N741	For communications applications below 60mc. 300mw device dissipation. Power gain of 22db at 30mc. Excellent video amplifier. TO-18 case.

FOR MEDIUM POWER TRANSMITTER APPLICATIONS

2N1561	Provides ½ watt RF power output at 160mc with 10db gain. Useful from below 70mc to 350mc.
2N1562	Companion driver for 2N1561.

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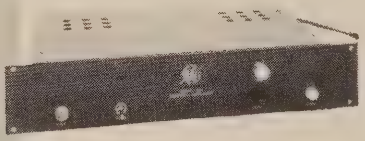
(Continued on page 96A)

Wide Band Amplifier Model 530



GENERAL DESCRIPTION

The Model 530 Wide Band Amplifier has been designed to fill a need for an amplifier used principally for voltage amplification of CW or pulsed signals.

This model has many applications in the laboratory and also for television distribution systems. It may be used to increase the output from signal sources within its frequency range, and its bandwidth of 300 mc's makes it ideal for amplifying millimicrosecond pulses.

PRICE $330.

SPECIFICATIONS

Bandpass	10 KC to 300 MC
Voltage Gain	18 db
Input Impedance	135 ohms
Output Impedance	150 ohms
Max. Output Power (into Matched Load)	.08W
Max Output Voltage (into Matched Load)	3.5 Vrms
Max. Peak Pluse Output	7 V pos. or neg.
Rise Time	Less than 2x10^{9} sec
Dimensions	19″ front panel—16″ wide, 9″ deep 3½ high. Power supply included.
Gain Control	Provided on front panel
Tube Complement	Two cascaded stages of eight 6AK5

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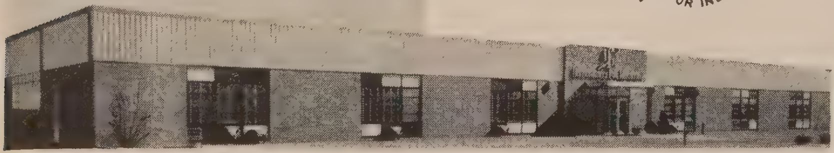

Graduate engineers with two or more years of circuit application in the fields of electronics or physics are invited to meet with Mr. John Hicks in an informal interview or send complete resume to: Dir. Personnel, IFI, 101 New South Road, Hicksville, New York.

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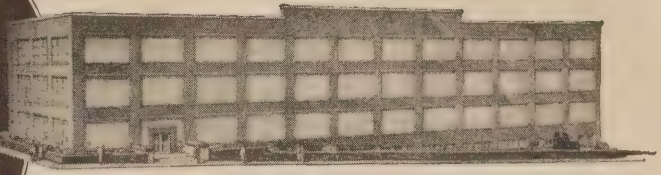
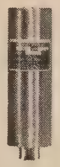
Watch Master ELECTRONICS



Our instruments, 40 to 30,000 cycles, are used extensively by industry and on government projects where enduring accuracy and maximum durability are required. Your inquiries on related products are invited.

PRECISION FORK OSCILLATOR UNITS

TYPE 2003



Size 1½" dia. x 4½" H. Wght. 8 oz.

Frequencies: 200 to 4000 cycles

Accuracies:—
  Type 2003 (±.02% at —65° to 85°C)
  Type R2003 (±.002% at 15° to 35°C)
  Type W2003 (±.005% at —65° to 85°C)

Double triode and 5 pigtail parts required.

Input, Tube heater voltage and B voltage

Output, approx. 5V into 200,000 ohms

TYPE 2007-6

TRANSISTORIZED, Silicon Type

Size 1½" dia. x 3½" H. Wght. 7 ozs.

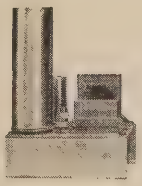
Frequencies: 360 to 1000 cycles

Accuracies:
  2007–6 (± .02% at —50° to + 85°C
  R2007–6 (±.002% at +15° to + 35°C
  W2007–6 (±.005% at —65° to + 85°C

Input: 10 to 30 Volts, D. C., at 6 ma.

Output: Multitap, 75 to 100,000 ohms

TYPE 2001-2



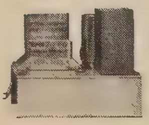
Size 3¾" x 4½" x 6" H., Wght. 26 oz.

Frequencies: 200 to 3000 cycles

Accuracy: ±.001% at 20° to 30°C
Output: 5V. at 250,000 ohms
Input: Heater voltage, 6.3 - 12 - 28

B voltage, 100 to 300 V., at 5 to 10 ma.

ACCESSORY UNITS FOR 2001-2



L—For low frequencies multi-vibrator type, 40-200 cy.

D—For low frequencies counter type, 40-200 cy.

H—For high freqs, up to 30 KC.

M—Power Amplifier, 2W output.

P—Power supply.

PRECISION FREQUENCY STANDARDS

TYPE 2005A

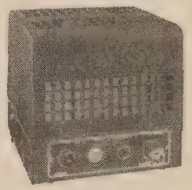
Size 8" x 8" x 7¼" High
Weight, 14 lbs.

Frequencies:
50 to 400 cycles (Specify)

Accuracy:
±.001% from 20° to 30°C

Output, 10 Watts at 115V

Input, 115V. (50 to 400 cy.)



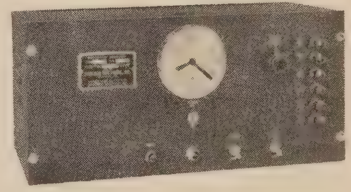
TYPE 2121A

Size
8¾" x 19" panel
Weight, 25 lbs.

Output: 115V
60 cycles, 10 Watt

Accuracy:
±.001% 20° to 30°C

Input,
115V (50 to 400 cy.)



TYPE 2111C

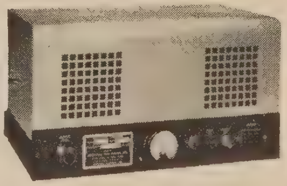
Size, with cover
10" x 17" x 9" H.
Panel model
10" x 19" x 8¾" H.
Weight, 25 lbs.

Frequencies: 50 to 1000 cy.

Accuracy:
(±.002% at 15° to 35°C)

Output: 115V, 75W.

Input: 115V, 50 to 75 cy.



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check list

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☐ Robertson Splice & Connector Cases
☐ Sperry Semiconductors
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☐ Sprague Capacitors

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☐ Immediate Delivery
☐ Quality control
☐ Complete inventories
☐ Nationwide service
☐ Competitive pricing

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Westbury, L. I. Sunnyvale, Cal. Waltham, Mass.

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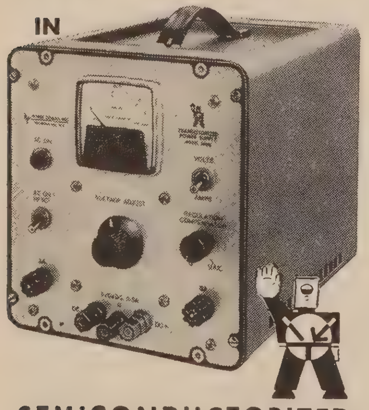
IN



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(Continued on page 98A)

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NEW DOUBLE USE MIL-R-94B Style RV6 ½" Dia. ¾ Watt VARIABLE RESISTOR

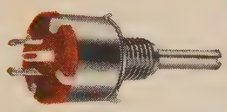
UNIQUE CARBON-CERAMIC ELEMENT Helps 1 Control Do 2 Jobs:

1 Surpass MIL-R-94B Style RV6 stability under military environmental conditions including moisture resistance and thermal cycling.

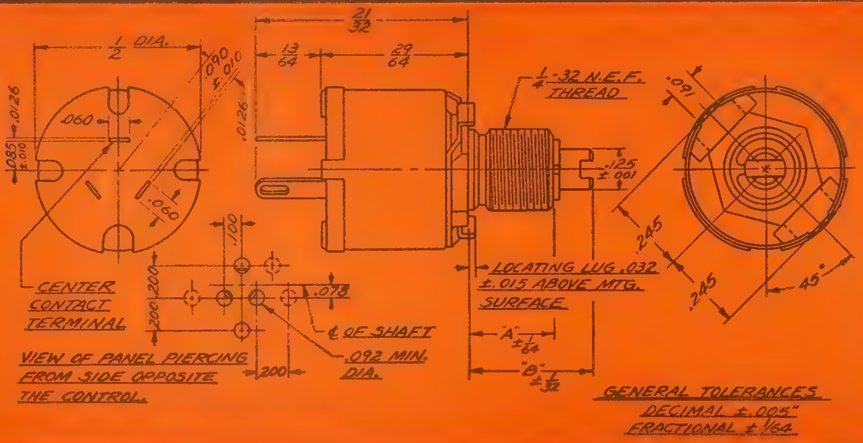
2 Provide full ¾ watt power rating @ 70°C with derating to zero at 150°C on most values (25% to 50% better than MIL-R-94B Style RV6) for higher load and temperature applications. Result of efficient ceramic-to-metal heat sink.

Other Features:

- High insulation resistance.
- Internal hi temp 0 ring seal between shaft and bushing.
- For better continuity and reliability, resistance element has double contactor paddles with adequate spring range.



SERIES 300. Actual Size


1/2 DIA.
.090 ±.010
21/32
13/64
29/64
1/4-32 N.E.F. THREAD
.091
.0126
.0126
.060
.085 ±.010
.060
.100
.125 ±.001
.245
.245
45°
CENTER CONTACT TERMINAL
.200
.200
.078
LOCATING LUG .032 ±.015 ABOVE MTG. SURFACE
℄ OF SHAFT
"A" ±1/64
"B" ±1/32
VIEW OF PANEL PIERCING FROM SIDE OPPOSITE THE CONTROL.
.200
.092 MIN. DIA.
GENERAL TOLERANCES
DECIMAL ±.005"
FRACTIONAL ±1/64

Specifications

Resistance Range:	1000 ohms thru 1 megohm (linear taper). Tolerances ±20% or ±10%.
Wattage & Temp. Rating:	¾ watt at 70°C derated to no load at 150°C (1K to 250K and 120°C on values over 250K) with 350 VDC max. safe operating voltage across end terminals. (Compares to ½ watt and 120°C in MIL-R-94B).
Stability:	Exceeds MIL-R-94B, Characteristic Y.
Rotation Angle:	295° ± 3°.
Shaft Dia.:	.125" ± .001".
Shaft Length:	Variable in ⅛" increments.
Shaft Trim:	Available with MIL-R-94B, style RV6 standard .031" ± .005" wide x .031" + .010" − .000" screwdriver slot. Flats also available.
Standard Mounting Bushings:	MIL-R-94B style RV6 standard ¼" −32 N.E.F. −2A by ¼" long non-locking bushing and ¼" −32 N.E.F. −2A by ½" long locking bushing.
Other Mounting Bushings:	¼" −32 N.E.F. −2A by ⅜" long locking and non-locking bushing.
Special Construction:	Waterseal bearing.

Immediate delivery on standard types from distributors' stocks.

CTS manufactures a complete line of composition and wirewound variable resistors for military, industrial and commercial applications. CTS Specialists will gladly help solve your variable resistor problems. Contact your nearest CTS office today.

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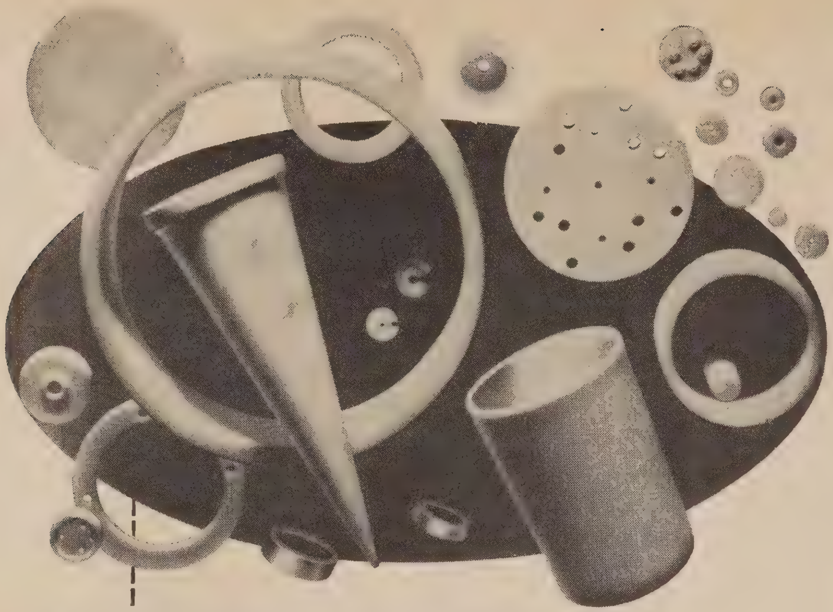

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(Continued on page 100A)

TASK FOR THE FUTURE

Since its inception nearly 23 years ago, the Jet Propulsion Laboratory has given the free world its first tactical guided missile system, its first earth satellite, and its first lunar probe.

In the future, under the direction of the National Aeronautics and Space Administration, pioneering on the space frontier will advance at an accelerated rate.

The preliminary instrument explorations that have already been made only seem to define how much there is yet to be learned. During the next few years, payloads will become larger, trajectories will become more precise, and distances covered will become greater. Inspections will be made of the moon and the planets and of the vast distances of interplanetary space; hard and soft landings will be made in preparation for the time when man at last sets foot on new worlds.

In this program, the task of JPL is to gather new information for a better understanding of the World and Universe.

> *"We do these things because of the unquenchable curiosity of Man. The scientist is continually asking himself questions and then setting out to find the answers. In the course of getting these answers, he has provided practical benefits to man that have sometimes surprised even the scientist.*
>
> *"Who can tell what we will find when we get to the planets? Who, at this present time, can predict what potential benefits to man exist in this enterprise? No one can say with any accuracy what we will find as we fly farther away from the earth, first with instruments, then with man. It seems to me that we are obligated to do these things, as human beings."*
>
> DR. W. H. PICKERING, *Director, JPL*

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A Research Facility operated for the National Aeronautics and Space Administration
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Send professional resume, with full qualifications and experience, for our immediate consideration

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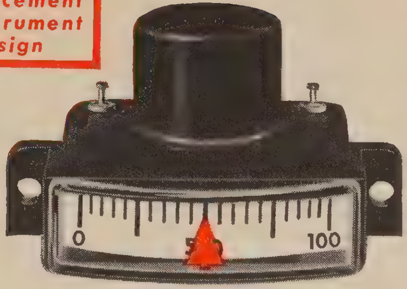
advancement
in instrument
design



EDGEWISE METER

Large, easily read display (1 7/16" scale) in only 9/16" x 1 7/8" panel space. For horizontal or vertical mounting. Miniature, self-shielded Coaxial mechanism has stability and durability of larger instruments. Weight 1.7 oz. Supplied with combination mounting bracket and bezel (not shown). Data on request. Marion Instrument Division, Minneapolis-Honeywell Regulator Co., Manchester, New Hampshire, U.S.A. *In Canada, Honeywell Controls Limited, Toronto 17, Ontario.*

Honeywell
First in Control
75th YEAR PIONEERING THE FUTURE
SINCE 1885

JKTO-23
Crystal-Controlled
Transistorized
Oscillator
100 KC
AVAILABLE NOW

A **precision 100 KC** plug-in signal source, currently in volume production. Incorporates a new, ultra-stable, 100 KC glass-sealed crystal design, and all-silicon solid state devices. Temperature controller incorporates precise long-lifed, glass-sealed Edison-type thermostat. Meets applicable mil. specs., including shock and vibration over a 5 to 2000 cycle range.

SPECIFICATIONS
STABILITY CLASS: 5 x 10^{-7}/Day.
FREQUENCY: 100 KC (Other frequencies available).
OUTPUT: One volt into 5000 ohms.
POWER: 28 volt DC (Other voltages available). Built-in Zener voltage regulator.
VIBRATION: 5 G's — 5 to 2000 cycles — less than one part per million.
ALTITUDE-HUMIDITY: Available sealed or unsealed.
TEMPERATURE RANGE: From −55°C to +85°C.
DIMENSIONS: 1-7/8" x 1½" x 4⅜ H. Weight: 6¼ Ounces.

For information, write stating requirements

THE JAMES KNIGHTS
COMPANY
Sandwich, Illinois

JK
JAMES KNIGHTS CO.
SANDWICH, ILL. U.S.A.
JKTO-23
100 KC
80°C

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(Continued from page 98A)

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Morley, R. A., Saugus, Mass.
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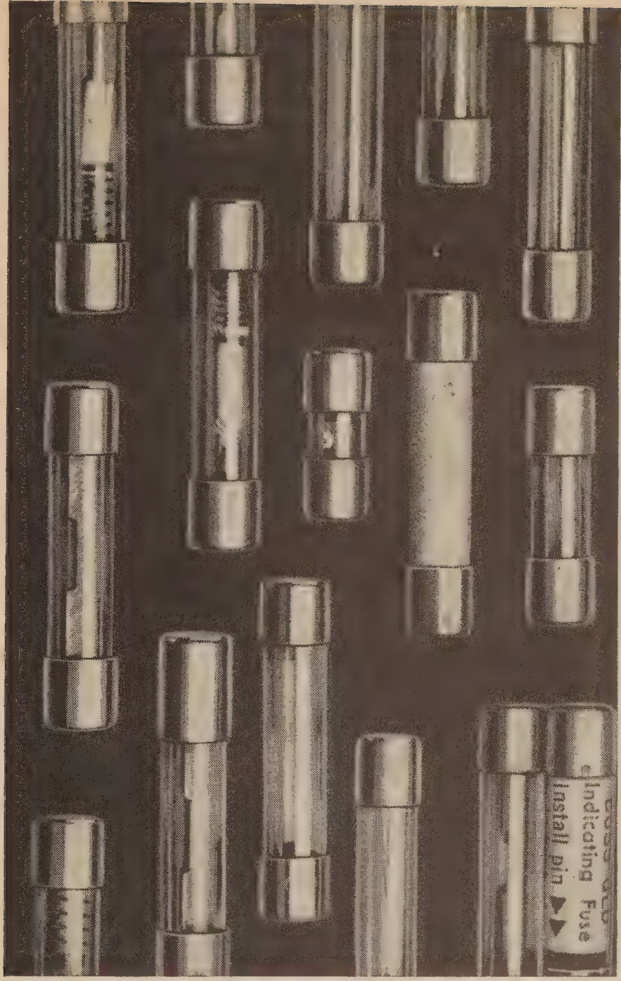
(Continued on page 102A)



SLOW BLOWING
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FUSES
Another outstanding development by the makers of BUSS FUSES
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Why "Experiment"...

with electrical protective devices

when BUSS fuses have proven their dependability?

With the many types of electrical protective devices on the market, perhaps you have asked yourself, "Which line is best for me?".

It doesn't pay to "experiment".

Protective devices that fail to protect or that open needlessly may reflect on the quality and reliability of your product — which in turn can affect your sales curve.

BUSS and FUSETRON fuses, on the other hand, *do* provide dependable electrical protection under all service conditions . . . and have for the last 45 years in the home, in industry and on the farm.

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Every BUSS and FUSETRON fuse is tested in a sensitive electronic device that automatically rejects any fuse not correctly calibrated, properly constructed and right in all physical dimensions.

Complete Line. There is a complete line of BUSS fuses in sizes from 1/500 ampere up . . . plus a companion line of fuse clips, blocks and holders.

If your protection problem is unusual . . . let the BUSS fuse engineers work with you and save you engineering time. If possible, they will suggest a fuse already available in local wholesalers' stock so that your products can be easily serviced wherever sold.

For more information on the complete line of BUSS and FUSETRON Small Dimension Fuses and Fuseholders, write for Bulletin SFB.

BUSSMANN MFG. DIVISION
McGraw-Edison Co.
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660

BUSS fuses are made to protect – not to blow, needlessly

BUSS makes a complete line of fuses for home, farm, commercial, electronic, electrical, automotive and industrial use

FUSETRON
TRUSTWORTHY NAMES IN ELECTRICAL PROTECTION
BUSS

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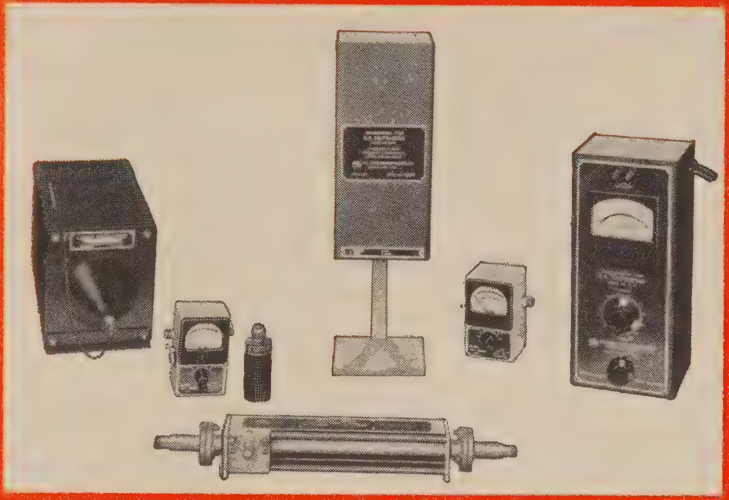
MicroMatch®

RF POWER STANDARDS LABORATORY



MicroMatch equipment is used to establish a reference standard of RF power to an accuracy of better than 1% of absolute.

THE 64IN CALORIMETRIC WATTMETER establishes RF power reference of an accuracy of 1% of value read, and is used to calibrate other wattmeters. Five power scales, 0-3, 3-10, 10-30, 30-100, and 100-300 watts, are incorporated in the wattmeters for use in the 0-3000 mcs range.

711N and 712N FEED-THROUGH WATTMETERS, after comparison with the 64IN, can be used continuously as secondary standards and over the same frequency range as covered by the primary standard. The MODEL 711N is a multirange instrument covering power levels from 0 to 300 watts in three ranges, 0-30, 30-75, and 75-300 watts. MODEL 712N covers power levels of 0 to 10 watts in three switch positions, 0-2.5, 2.5-5, and 5-10 watts full scale.

636N and 603N RF LOAD RESISTORS absorb incident power during measurements. MODEL 636N is rated at 600 watts, and MODEL 603N is rated at 20 watts. Both models perform satisfactorily over the entire frequency range to 3000 mcs. These loads, in conjunction with the MODELS 711N and 712N Feed-through Wattmeters, form excellent absorption type Wattmeters.

152N COAXIAL TUNER is used to decrease to 1.000 the residual VSWR in a load. The tuner is rated at 100 watts, and its frequency range is 500-4000 mcs.

For more information on Tuners, Directional Couplers, R. F. Loads, etc., write

M.C. Jones

M. C. JONES ELECTRONICS CO., INC.
185 N. MAIN STREET, BRISTOL, CONN.
SUBSIDIARY OF
THE Bendix CORPORATION

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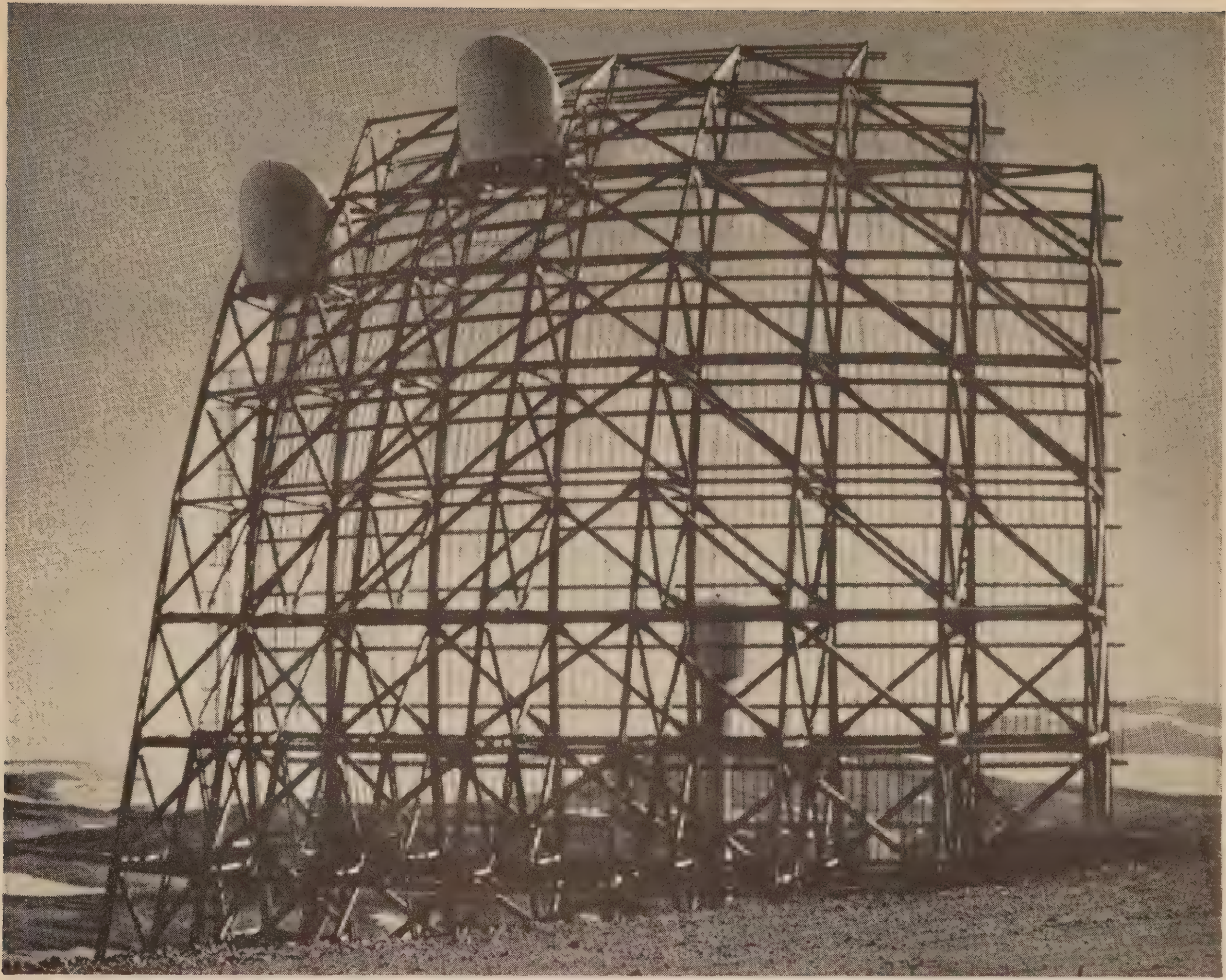
Stettinger, R. L., New York, N. Y.

(Continued on page 104A)



Note the offset parabolic relay antennas mounted on the tropo-scatter antenna. Designed with integral radomes protecting the feed and reflecting surface, these units were erected by KENNEDY for base communications use — another indication of KENNEDY's all-around capabilities in the antenna art.

when you're thinking about

TROPO-SCATTER ANTENNA SYSTEMS

...you should be talking to D. S. KENNEDY & CO.

The KENNEDY antenna pictured, is but one model of the world's most complete line of tropo-scatter antennas, including 60 foot models of steel or aluminum, 28 foot aluminum, 28 foot transportable models plus 120 footers like the one pictured.

Erected by General Electric Company's Communication Products Department in the arctic, KENNEDY antennas like this were selected for the job for several reasons:

1. **ENGINEERED FOR TOUGHEST ENVIRONMENT**: Arctic winds often exceed hurricane force, and these tropo-scatter units will withstand winds of more than 180 mph when loaded with 6″ of ice.
2. **ENGINEERED FOR CONTINUOUS DUTY**: Operating tolerances are strictly maintained. KENNEDY structural know-how keeps antennas accurate under wind or ice loads.
3. **ENGINEERED TO ADVANCED CONCEPTS**: KENNEDY antennas utilize offset feed systems, separately mounted feed towers and are designed for easy erection in the field.
4. **BUILT-IN PRECISION**: KENNEDY quality control and precision construction at the plant assures minimum field time and maximum performance.
5. **COMPLETE SYSTEMS**: Wave guides, feed horn, feed tower, and reflectors are integrated into a unit by KENNEDY. This saves time and improves the performance of all the components.

D. S. KENNEDY & CO. has been associated with the design, manufacture, and erecting of the greatest variety of tropo-scatter antennas. That's why it will pay you to talk to them.

Kennedy gives you experience you can't buy elsewhere.

D. S. KENNEDY & CO.

Kennedy Antenna Division, Cohasset, Mass.
EVergreen 3-1200 Twx COH 311

Anchor Metals Division, Hurst, Texas
(Fort Worth) ATlas 4-2583

TRACKING ANTENNAS • RADIO TELESCOPES • RADAR ANTENNAS • SCATTER COMMUNICATIONS ANTENNAS • MICROWAVE RESEARCH AND DEVELOPMENT • TRANSMISSION TOWERS • SWITCHYARD STRUCTURES

NOW
there are
4
high-performance Series F
Tarzian Silicon Rectifiers

The addition of Type 2F4 expands the Tarzian F Series to cover a current range from 200 to 750 milliamperes dc (to 85° C). Characteristics of the complete F Series are shown below, in condensed form.

COMPARE THESE ADVANTAGES:

- **Small Size**...diameter 3/16″ max; length 5/16″ max.
- **Low Cost**...*and* high quality resulting from Tarzian production methods
- **Insulated Body**...no mounting problems
- **High Efficiency**...oversize junction and low voltage drop
- **Available**...*now* from stock

In addition to providing good operating efficiency at low temperature rise, thereby increasing reliability, the *oversize* junction also handles inrush currents far beyond normal circuit requirements. Careful selection of materials increases stability and improves thermal characteristics.

For additional information about Series F rectifiers, call your Sarkes Tarzian sales representative, or write Section 4887 F. Sarkes Tarzian is a leading supplier of silicon, tube replacement, and selenium rectifiers. Practical application assistance is always available.

Tarzian Type	Amps. DC (85° C)	PIV	Max. RMS Volts	Max. Amps. Recurrent Peak	Max. Amps. Surge (4MS)
2F4	.20	400	260	2.0	20
F-2	.75	200	140	7.5	75
F-4	.75	400	280	7.5	75
F-6	.75	600	420	7.5	75

SARKES TARZIAN, INC.
World's Leading Manufacturers of TV and FM Tuners • Closed Circuit TV Systems • Broadcast Equipment • Air Trimmers • FM Radios • Magnetic Recording Tape • Semiconductor Devices
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(Continued from page 102A)

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(Continued on page 106A)

IS *YOUR* COMPANY ON THE *OFFENSE* FOR *DEFENSE?*

SIGNAL is your introduction to the men who control the growing $4 billion dollar government radio-electronics spending

Never before have our armed forces so badly needed the thinking and products of the electronics industry. Advertising in SIGNAL, the official journal of the *Armed Forces Communications and Electronics Association*, puts you in touch with almost 10,000 of the most successful men in the field—every one a prospect for your defense products!

Share in the defense and the profits! Company membership in the AFCEA, with SIGNAL as your spokesman, puts you in touch with government decision-makers!

SIGNAL serves liaison duty between the armed forces and industry. It informs manufacturers about the latest government projects and military needs, while it lets armed forces buyers know what *you* have to offer to contribute to our armed might. SIGNAL coordinates needs with available products and makes developments possible.

But SIGNAL is more than just a magazine. It's *part of an over-all plan!*

A concerted *offensive* to let the government, which has great faith in industry and the private individual producer, know exactly what's available to launch its far-sighted plans. Part of this offensive is the giant AFCEA National Convention and Exhibit (held this year in Washington, D.C., June 3-5). Here, you can *show* what you have to contribute directly to the important buyers. Your sales team meets fellow manufacturers and military purchasers and keeps "on top" of current government needs and market news.

Besides *advertising* in SIGNAL which affords year-round exposure by focusing your firm and products directly on the proper market . . . besides *participation* in the huge AFCEA National Convention and Exhibit . . . the over-all plan of company membership in the AFCEA *gives your firm a highly influential organization's experience and prestige to draw upon.*

As a member, you join some 170 group members who feel the chances of winning million dollar contracts are worth the relatively low investment of time and money. On a local basis, you organize your team (9 of your top men with you as manager and team captain), attend monthly chapter meetings and dinners, meet defense buyers, procurement agents and sub-contractors. Like the other 48 local chapters of the AFCEA, your team gets to know the "right" people.

In effect, company membership in the AFCEA is a "three-barrelled" offensive aimed at putting your company in the "elite" group of government contractors—the group that, for example in 1957, for less than $8,000 (for the full AFCEA plan) made an amazing total of *459.7 million dollars!*

This "three-barrelled" offensive consists of

(1) Concentrated advertising coverage in SIGNAL, the official publication of the AFCEA;

(2) Group membership in the AFCEA, a select organization specializing in all aspects of production and sales in our growing communications and electronics industry; and

(3) Attending AFCEA chapter meetings, dinners and a big annual exposition for publicizing your firm and displaying your products.

If *you're* in the field of communications and electronics . . . and want prestige, contacts and exposure . . . let SIGNAL put your company on the *offense* for *defense!* Call or write for more details—now!

SIGNAL

BPA

Official Journal of AFCEA

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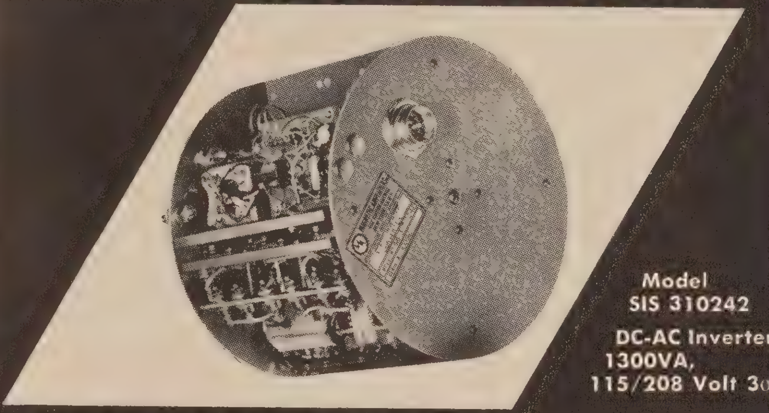
ARMED FORCES COMMUNICATIONS AND ELECTRONICS ASSOCIATION

New STANDARD LINE OF RELIABILITY ENGINEERED

STATIC INVERTERS

FOR AIRCRAFT, MISSILE, AND SPACE VEHICLE APPLICATIONS



Model SIS 310242

DC-AC Inverter 1300VA, 115/208 Volt 3φ

Inputs Nom. 28VDC Outputs Nom. 115V 400cps 1φ or 3φ
Power Ratings from 30VA to 1500VA

Space / Weight Designed To Yield Maximum Power Output Consistent With High Reliability And Performance

FEATURES

- PRECISION FREQUENCY
- OVERLOAD PROTECTION
- EXCELLENT WAVEFORM
- VOLTAGE REGULATED
- PHASE LOCKED CIRCUITRY
- REVERSE VOLTAGE PROTECTION

MODEL	POWER RATING	OUTPUT VOLTAGE	OUTPUT FREQUENCY	SPECIAL FEATURES
SIS-40311 series SIS-40511 series	30 VA 1φ 50 VA 1φ	115 VAC adjustable ± 10%	400 cps ± .01 to ± .05%	Precision frequency, excellent waveform, voltage regulated, ± 1% for line, ± 2% load.
SIS-408042 series	80 VA 1φ	115 VAC ± 5 V	400 cps ± 1%	Wide range stabilization, input 18-30 VDC, Voltage regulated ± 1½% no load to full load.
SIS-410042 series SIS-425041 series	100 VA 1φ 250 VA 1φ	115 VAC ± 5%	400 cps ± 1% LC. osc. tuneing fork	Magnetic Amplifier voltage regulated. Rapid on-off switching no transients high efficiency.
SIS-3-425042 series SIS-3-450022 series	250 VA 3φ 500 VA 3φ	115 VAC ± 2%	400 cps ± 2% ± 1%	Regulates to ± 2% with simultaneous variation of zero to full load, and line 25 volts to 29 volts.
SIS-3-47512 series	750 VA 3φ	208/115 V or 115/66.5 volts Adj. ± 5%	400 cps ± .002%	Extreme frequency accuracy. Phase lock circuitry. Magnetic voltage regulator.
SIS-3-40613 series	60 VA 3φ	26 VAC Adj. ± 5%	400 cps ± .01%	Short circuit protected, reverse voltage protection, high temp., + 100°C. Voltage regulated.

DESIGN NOTE: any of the special features described may be combined in a single unit to meet your special requirements.

MA

MAGNETIC AMPLIFIERS, INC.

632 TINTON AVENUE
NEW YORK 55, N. Y.
CYPRESS 2-6610

136-140 KANSAS STREET
EL SEGUNDO, CALIFORNIA
OREGON 8-2665

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(Continued from page 104A)

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Bogart, C. C., Rochester, N. Y.
Brautigam, E. H., Levittown, Pa.
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Friedman, M. S., Boston, Mass.
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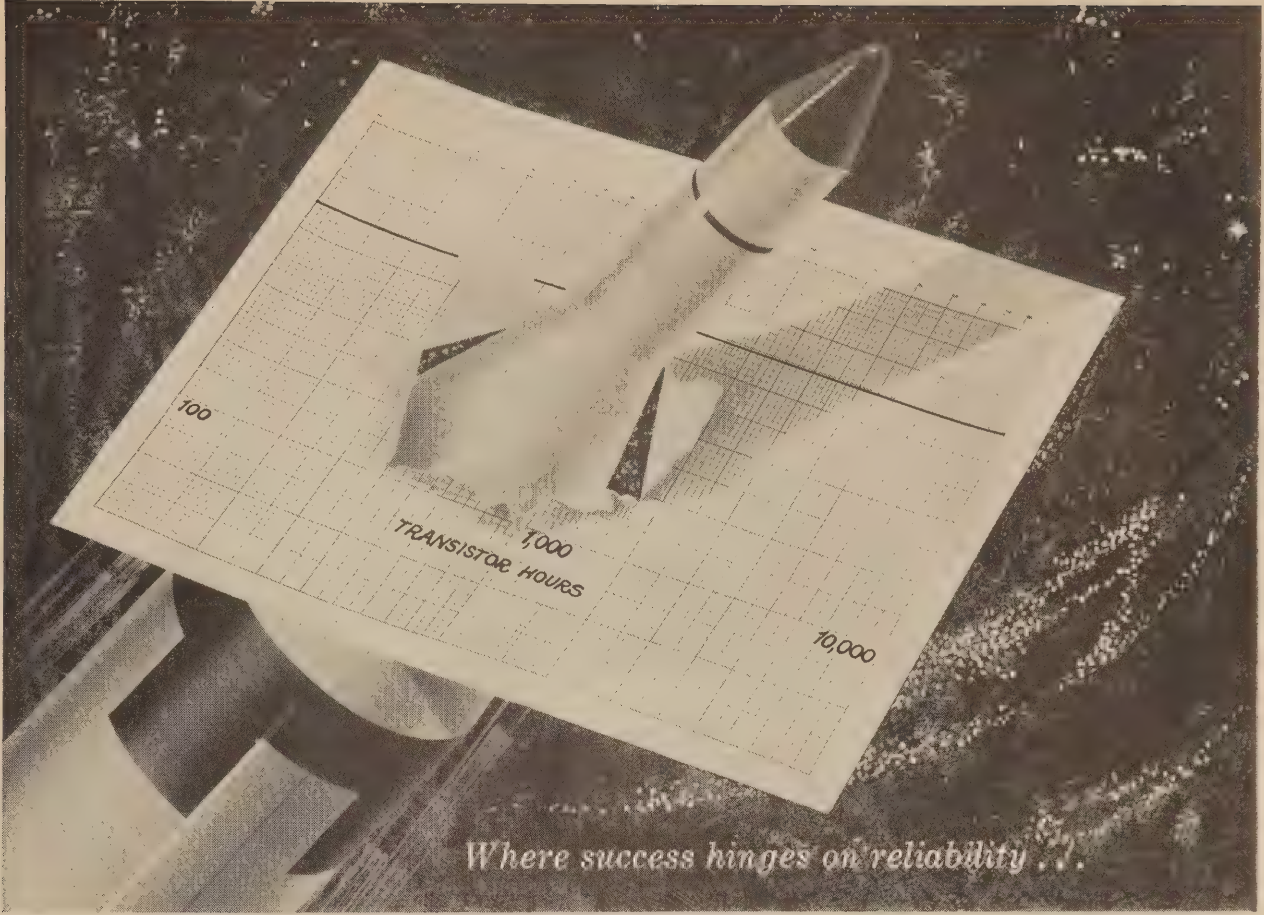
Koch, I. I., Brooklyn, N. Y.
Koudelka, O., Wayne, N. J.

(Continued on page 108A)



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2N327A	0.005	−40	15*	1200	30	65	200
2N328A	0.005	−35	30*	1400	30	65	300
2N329A	0.005	−30	60*	1500	30	65	400
2N1034	0.005	−40	15**	3000	30	65	200
2N1035	0.005	−35	30**	3000	30	65	300
2N1036	0.005	−30	60**	3000	30	65	400
2N1037	0.005	−35	30**	3000	15	65	250
2N1275	0.005†	−80	15**	3000	30	65	200
2N1623/ CK942	0.005	−20	25**	3000	30	65	200
2N1654	0.005†	−80	30**	3000	30	65	300
2N1655	0.005‡	125	15**	3000	30	65	200
2N1656	0.005‡	125	30**	3000	30	65	300

*$I_c = -3.0$ ma; $V_{CE} = -0.5$V † At 60 Vdc.
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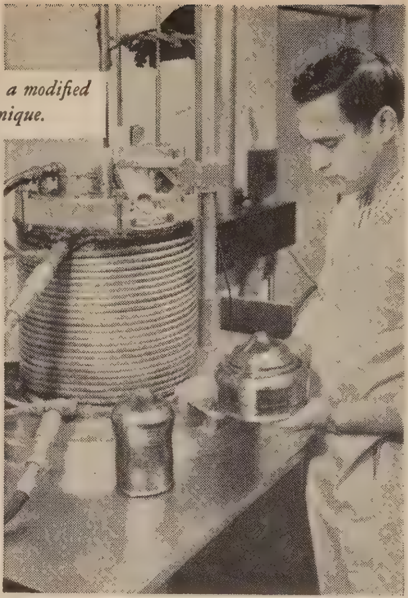

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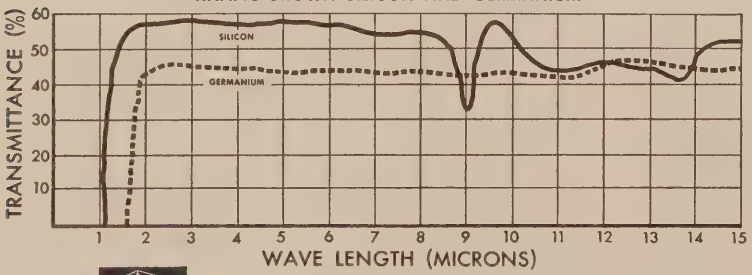

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(Continued on page 112A)

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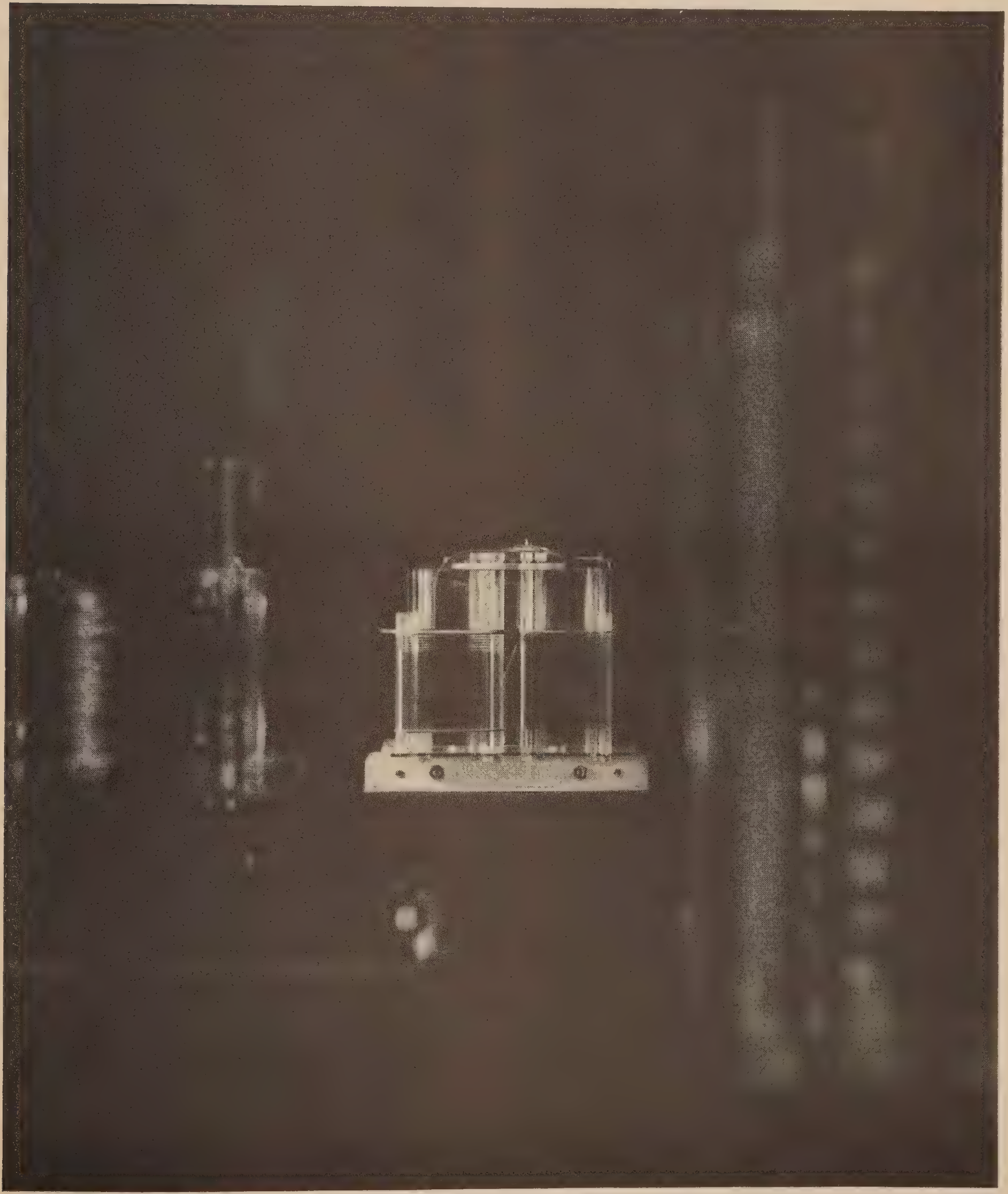

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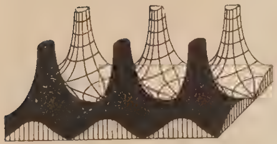
June, 1960
Vol. 48 No. 6

Proceedings of the IRE

Poles and Zeros



TASO: This Special Issue of the PROCEEDINGS publishes results of a study carried out by the Television Allocations Study Organization. At the request of the Federal Communications Commission the Study Organization was formed, in 1956, by the television industry. The object of the study was "to develop full, detailed and reliable technical information, and engineering principles based thereon, concerning present and potential VHF and UHF television service."

The Professional Group on Broadcasting, through the intense interest and cooperation of its members, has assembled this Special Issue. The Editorial Board expresses its appreciation to the many PGBC members who helped by reviewing the papers; to the Administrative Committee of the PGBC for providing the underlying support; to Raymond F. Guy, former IRE President, for encouragement and help; and, in particular, special thanks to the PGBC Chairman, George F. Hagerty, and to George R. Town, formerly Executive Director of TASO.

The findings of the two and one-half year study comprise an assembly of vital new information which is of inestimable value nationally and internationally. A perusal of the issue will demonstrate how effectively and thoroughly TASO consummated its assigned task. The PROCEEDINGS is pleased to be the vehicle to publish this work for the profession.

Research Goals: A Conference on Research Goals, sponsored by the National Science Foundation in cooperation with fifteen professional societies (of which IRE was one), was held last December at Worcester Polytechnic Institute under the chairmanship of Arthur Bronwell, President of Worcester Polytechnic Institute. Through President Bronwell's cooperation, Poles and Zeros is making a brief report on this Conference to the IRE membership.

The specific question posed to the Conference was: "How can young research scientists and engineers be brought more stimulatively, imaginatively, and creatively into contact with the frontiers of science and technology in such a way as to accelerate significant discovery, both in the advancement of science and in translation of science into new technology?" Fifty-one of the nation's leading educators, research scientists, and engineers examined the basic issues in a two-day session. Out of this examination emerged the general conclusion that "Our nation's scientific and technological progress could be greatly accelerated if conditions more favorable to achieving bold, imaginative pioneering in basic research and in technological innovation could be realized."

The detailed report of the Conference includes specific recommendations to colleges and universities and to scientific and engineering societies. The seven recommendations to scientific and engineering societies follow:

"1. Establish more effective practices which will increase the attendance and participation of talented, young members at meetings of scientific and engineering societies. Develop programs which will bring these young people into stimulative personal association with leading scientists and engineers.

"2. Encourage the presentation and publication of papers of a philosophical nature which look to the future of science and technology. Invited speakers, who are pioneers in research thought, could do much to lift the visions and ambitions of talented young people to more promising research goals.

"3. Develop comprehensive programs for digesting the state of the art. Young people are confused by the disorganized state of research knowledge. A comprehensive study, now completed as a project of the National Science Foundation, which outlines the state of the art and future research possibilities in the various fields of astronomy is the sort of compilation which could be exceedingly helpful in many fields.

"4. Establish society meetings for the purpose of developing a more effective interchange of ideas between scientists and engineers in research areas of broad mutual interest This cross-fertilization of ideas among scientists and engineers is becoming increasingly important and is not nearly as effective as it should be.

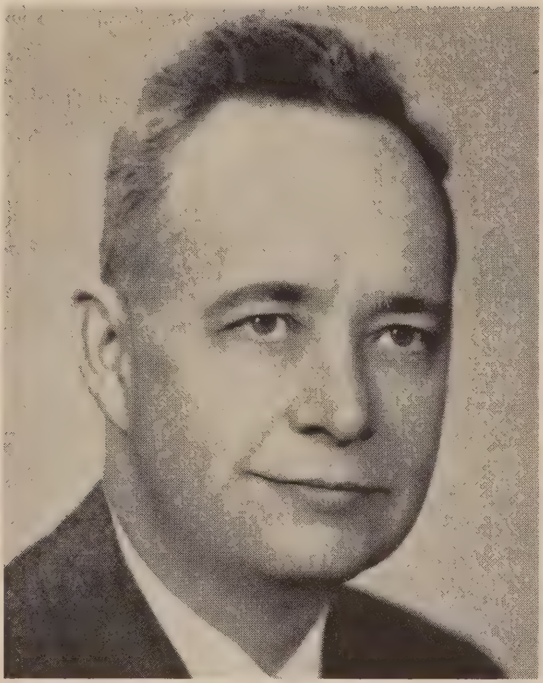
"5. Establish free forums at engineering society conventions where any member can make a short presentation of his creative work, allowing the widest latitude of subject matter, with no publication requirement, except in abstract form. These presentations should be handled without critical review by society committees, which occasionally emasculate original work. Such sessions are regular practice in some scientific societies but as yet have not been adopted by the engineering societies. They provide rapid interchange of experiences and a highly effective means of bringing current research to the attention of the society membership without cluttering up the publications.

"6. Actively promote and encourage financial support for research. Consider the possibility of the Society itself sponsoring research using funds contributed by industry. Some trade associations have been highly effective in this kind of operation.

"7. Recognizing that creativity begins in the individual at an early age, foster among the Society members a recognition of the contribution which they can make individually by stimulating the creative development of youth. This can be accomplished by undertaking youth projects in their own homes, by youth programs developed in their business establishments, or by other means which will encourage young people to develop ideas and which will give them the means of implementation."

The IRE should consider the extent to which it is already achieving the intent of these recommendations and the steps that it might institute to further achieve these desirable goals.

—F.H., Jr.



P. E. Haggerty

Director, 1960

Patrick E. Haggerty (A'45–SM'53–F'58) was born March 17, 1914 in Harvey, N. D. He received the B.S.E.E. degree in 1936 from Marquette University, Milwaukee, Wis. From 1949 to 1951 he did part-time graduate work at Southern Methodist University, Dallas, Texas. In 1959 he received an honorary LL.D. degree from St. Mary's University, San Antonio, Texas.

From 1935 to 1942 he was employed by the Badger Carton Company, Milwaukee, Wis. While still a student, he worked at the company as a cooperative student engineer. Following graduation he became production manager of the company. He later became Assistant General Manager with responsibility for all engineering, manufacturing and administrative functions except sales.

During World War II he served as a lieutenant, U. S. Naval Reserve, in the Bureau of Aeronautics, Department of the Navy, Washington, D. C. In 1945 he joined Geophysical Service Inc. as General Manager of the Laboratory and Manufacturing Division. This organization eventually became the company that is now known as Texas Instruments Inc. In 1950 Mr. Haggerty became Executive Vice President and Director of Texas Instruments, and in 1959 he was elected President. He also serves as Director or officer in major wholly-owned subsidiaries.

Mr. Haggerty is Section Advisor for the Dallas Section of the IRE. He is a member of the General Management Division Planning Council of the American Manufacturers Association; a member of the Board of Directors of Texas Manufacturers Association; and a former vice chairman of the Board of Trustees of the National Security Industrial Association. He is also a member of the American Association for the Advancement of Science, the Society for Exploration Geophysicists, the American Ordnance Association, and the Navy League of the United States, Sigma Phi Delta, Tau Beta Pi and Alpha Sigma Nu.

Television Allocations Problems*

E. W. ALLEN†, FELLOW, IRE

Summary—**The Television Allocations Study Organization was established by the television industry in September, 1956, at the request of the Federal Communications Commission, to make a thorough analysis of the engineering aspects of problems relating to the television broadcast allocations. This paper relates the needs underlying the request and gives a brief history of television allocations, culminating in the events leading to the formation of TASO.**

THE TECHNICAL problems relating to the provision of an effective allocation of radio-frequency bands for television broadcasting and to the assignment of frequencies within the bands to television broadcasting stations have always been particularly difficult ones. The early experimentation on television broadcasting, about 1930 and before, took place in the upper part of the medium-frequency band. It soon became evident that the available channel widths and other characteristics of these frequencies were not suitable, and in 1931 the Television Standards Committee of the Radio Manufacturers Association (RMA) recommended to the Federal Radio Commission (FRC) the allocation of channels in the VHF region of the spectrum.

A general allocation hearing was held by the Federal Communications Commission (FCC, successor to the FRC) in 1936, at which the RMA and other industry witnesses provided information which showed the general suitability of the VHF for television broadcasting. In the allocation table prepared as a result of this and further hearings, and issued in 1937, television was allocated nineteen VHF channels, each six megacycles per second in width. As a corollary to the allocation, the industry group known as the first National Television Systems Committee produced a set of transmission standards which were adopted by the FCC in 1941.

The Radio Technical Planning Board was formed in 1943 at the request of the FCC, to plan for the rapid expansion which occurred in the uses of radio as a result of the war effort. Panel 6 of the Board, dealing with television, recommended that a minimum of 30 channels be allocated. However, because of the demands of other services, the FCC allocated only 13 VHF channels, shared by the mobile services, and supplemented by 440 megacycles of spectrum space in the UHF. Because of the small number of VHF channels which it found possible to allocate to television, the FCC stated in its decision that television must look to the UHF as its ultimate home. The situation was further complicated by the withdrawal of Channel 1 in 1948, in order to eliminate the sharing by the mobile services. Several attempts have been made by the FCC and the industry to solve the problem of inadequate VHF allocations, but to date the solution has eluded these efforts.

In 1948, the Radio-Television Manufacturers Association and the IRE joined to form the high-level Joint Technical Advisory Committee (JTAC), whose first major project was, at the request of the FCC, a study of the possibility of using UHF for television broadcasting. Following its report to the FCC on this question, JTAC undertook a comprehensive study of the entire allocations problem which culuminated in 1952 in the publishing of its treatise on "Radio Spectrum Conservation."

In the meantime, as television broadcasting spread across the country, disturbing reports of unexpectedly large and frequent cases of interference between stations were heard in ever increasing number. To be certain that the situation would not deteriorate completely, the FCC in 1948 issued its "freeze" order, under which further licensing of television broadcasting stations was suspended pending a study of the engineering aspects of allocations, especially of propagation phenomena. This was followed by the appointment of the FCC *Ad Hoc* Committee on Propagation. The VHF propagation curves prepared by this Committee and a set of UHF curves prepared at the FCC formed a part of the technical basis for the allocations table issued by the FCC in its Sixth Report and Order which ended the "freeze" in 1952. This table included, for the continental United States, 498 commercial VHF and 1271 commercial UHF assignments, plus 233 educational assignments of which 71 were in the VHF and 162 in the UHF regions.

The need in 1956 for a comprehensive, up-to-date study of the engineering factors underlying television allocations was brought about by a dilemma faced by the FCC which was not visualized when the Sixth Report and Order was issued. Since that time, there had been an increasing demand for television channels. Operation in the UHF region, however, had not been found to be nearly as successful as had been hoped by the Commission and the industry. As a consequence, prospective television broadcasters, while feverishly attempting to obtain scarce VHF channels, showed little interest in obtaining abundantly available UHF channels. The reasons for the lack of complete success of UHF television broadcasting were many and complex, involving commercial and competitive problems, as well as technical.

On June 26, 1956, the FCC released a public notice entitled "Long-Range and Interim Plan for Television Promotes Comparable Competitive Facilities." This notice summarized the Commission's actions in Docket

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* Original manuscript received by the IRE, February 15, 1960; revised manuscript received March 21, 1960.

† Federal Communications Commission, Washington, D. C.

11532 and terminated that rule making proceeding which had been instituted on November 10, 1955. Contained therein was a summary of the problems facing the Commission with respect to television. This notice points out the inadequacy of 12 VHF TV channels for a nationwide television system and notes that the opening of UHF to TV in 1952 was with the expectation that ultimately most television operation would be UHF. It further states that:

"Although it would be premature at this stage for the Commission to adopt final conclusions on such a shift, it believes that the effort to find a solution to the general TV allocation problem requires an exploration of whether UHF alone would render adequate service throughout the country, or whether it would be necessary to confine all-UHF television to areas, such as east of the Mississippi River. . . . Before it would be possible to achieve these advantages it would be necessary to find solutions for numerous problems which a transition to all-UHF television would involve. These problems fall into several major groups. The first group relates to the technical transmission and reception potentialities of UHF. It will be necessary to ascertain the extent to which UHF transmission and reception can be improved, in order to make a realistic determination as to whether conversion to all-UHF TV throughout the United States or in a major portion of the country would or would not result in the loss of services available now or potentially available with the use of VHF channels."

With this in mind, the Commission indicated a need for the launching of an expedited research and development program which should concentrate on development of UHF transmitters to produce increased power, the use of such techniques as UHF boosters and satellites and the development of receivers and receiving antennas, with the objects of increasing the sensitivity and reducing the noise factor of receivers, and improving receiver selectivity to reduce the number of restrictions on station separations. A number of other transitional problems were set forth. Comments on all these problems were requested to be directed to "FCC Inquiry Into the Feasibility of Transferring Television Broadcasting to the UHF Band."

As an outcome of this inquiry, the Commission issued, on August 31, 1956, a public notice calling a meeting of industry representatives on September 20 for the purpose of expediting research and development of UHF technical operation. Letters were addressed to the National Association of Radio and Television Broadcasters, Radio-Electronics-Television Manufacturers Association, Joint Council on Educational Television, Committee for Competitive Television, and the Association of Maximum Service Telecasters, Inc., announcing this meeting and setting forth an agenda for the meeting, with a proposal to establish a Television Allocation Research Committee (TARC).

The proposed objectives of TARC were set forth as follows:

1) To assemble facts relating to the feasibility of transferring the operation of television broadcasting to the present UHF spectrum space allocated to television.
2) If 1) is not feasible—to assemble the facts which support the best available alternatives.
3) To advise the Commission regarding the technical principles which should be applied in television channel allocation.

Subsequently, the Television Allocations Study Organization (TASO) was formed with the objectives stated as follows:

> "The objectives of this organization shall be to develop full, detailed and reliable technical information, and engineering principles based thereon, concerning present and potential VHF and UHF television service."

The problems which were assigned to TASO were wide in scope and difficult to solve. Essentially they evolve from the conclusion that 12 TV channels are insufficient for a nationwide competitive system of television, and that some means must be found for using the UHF television channels.

The Television Allocations Study Organization—A Summary of Its Objectives, Organization and Accomplishments*

GEORGE R. TOWN†, FELLOW, IRE

Summary—**During the past three years, a comprehensive study has been made of the engineering factors underlying the allocation of frequencies for television broadcasting. This work has been carried on by an industry-wide group known as the Television Allocations Study Organization (TASO). This paper outlines the objectives and organization of TASO, and summarizes the more significant findings relating to field strength measurement and analysis, field tests of television reception, laboratory studies of television picture quality, tropospheric wave propagation, and performance of receiving and transmitting equipment. The performance capabilities of UHF and VHF television broadcasting systems are compared.**

OBJECTIVES AND ORGANIZATION OF TASO

THE Television Allocations Study Organization was established late in 1956 by the television industry, in response to a request by the Federal Communications Commission (FCC) that a study be conducted of "the technical principles which should be applied in television channel allocation." Five organizations representing both television broadcasters and manufacturers of television equipment joined to sponsor TASO. These were the Association of Maximum Service Telecasters, representing high-power, principally-VHF broadcasters; the Committee for Competitive Television, representing UHF broadcasters; the Electronic Industries Association, representing manufacturers; the Joint Council on Educational Television, representing those interested in educational uses of television; and the National Association of Broadcasters, representing broadcasters in general. Representatives of these five organizations formed the TASO Board of Directors, the policy making group. These five organizations also paid the administrative expenses of TASO, while the operating expenses were borne by these same groups and by contributions from many broadcasters and manufacturers.

The objectives of TASO were stated as follows in the "Charter" which was drawn up by the Board of Directors. "The objectives of the organization shall be to develop full, detailed and reliable technical information, and engineering principles based thereon, concerning present and potential UHF and VHF television service. . . . TASO's functions shall be limited solely to technical study, fact finding and investigation, and interpretation of technical data." This statement was approved by the FCC.

After considering various alternatives, the Board of Directors concluded that the necessary studies should be carried on by groups, or panels, of engineers representing all phases of the television industry, in much the same manner that the standards for monochrome and for color television had been developed by the first and second National Television System Committees. The Board also concluded that a full-time executive director should administer the affairs of TASO during the most active part of its existence.

An analysis of the task facing TASO indicated that the engineering factors affecting television allocations could be divided into several classes. The first of these related to the characteristics of equipment, both transmitting and receiving. The second concerned wave propagation phenomena in both the service and interfering areas of a transmitter, and included the development of specifications for measuring field strength, the collection of propagation data, and the analysis of these data. The third factor was a determination of the limiting amounts of interference of various types which could be tolerated, still retaining a television picture which was satisfactory to the average observer. The fourth necessary task was a field study of television reception. Finally, there was the problem of the over-all analysis of the technical performance of the television system.

Six panels were established to carry out assignments roughly in accord with this outline of the tasks. The names of these panels and of their chairmen follow.

Panel 1—Transmitting Equipment, William J. Morlock;
Panel 2—Receiving Equipment, William O. Swinyard;
Panel 3—Field Tests, Knox McIlwain;
Panel 4—Propagation Data, Frank G. Kear;
Panel 5—Analysis and Theory, Robert M. Bowie;
Panel 6—Levels of Picture Quality, Charles E. Dean.

A total of over 40 committees, subcommittees, and task forces carried out studies of particular topics within the framework of the panel structure. The chairmen and vice chairmen of the panels, together with the executive director, formed the Panel Coordinating Committee, which had over-all responsibility for the engineering program. The organizational structure of TASO can best be visualized by study of Fig. 1.

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* Original manuscript received by the IRE, January 22, 1960.

† College of Engineering, Iowa State University, Ames; formerly Executive Director, Television Allocations Study Organization.

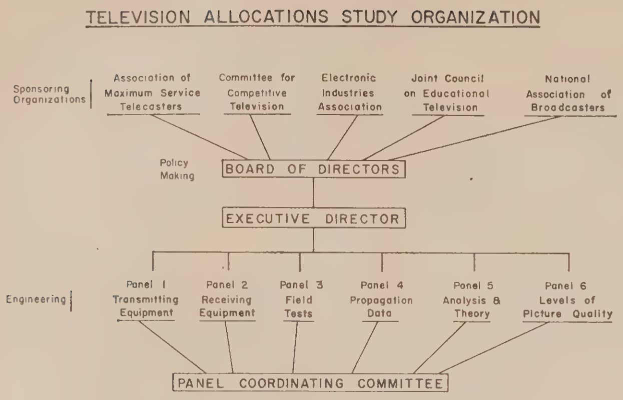
TELEVISION ALLOCATIONS STUDY ORGANIZATION
Sponsoring Organizations
Association of Maximum Service Telecasters
Committee for Competitive Television
Electronic Industries Association
Joint Council on Educational Television
National Association of Broadcasters
Policy Making
BOARD OF DIRECTORS
EXECUTIVE DIRECTOR
Engineering
Panel 1 Transmitting Equipment
Panel 2 Receiving Equipment
Panel 3 Field Tests
Panel 4 Propagation Data
Panel 5 Analysis & Theory
Panel 6 Levels of Picture Quality
PANEL COORDINATING COMMITTEE

Fig. 1—TASO organization chart.

A few statistics regarding the operation of TASO indicate the extent of its activities. A total of 271 leading engineers from 139 companies composed the membership of the six panels and their subsidiary committees. These men came from literally all branches of the television industry—from manufacturers of television transmitting, receiving, and measuring equipment, from television networks, from individual high- and low-power, UHF and VHF broadcasting stations, from consulting engineering firms, from educational institutions, from governmental agencies, from community television distribution groups, from technical publishing houses, and from the television service industry. Among them were 43 Fellows of the IRE. There were over 150 formal meetings of the Board of Directors, the Panel Coordinating Committee and the six panels, plus many meetings of committees, subcommittees, and task forces. A total of over 750 formal documents were issued by the TASO office. These ranged from single page agendas of meetings to reports hundreds of pages in length. The greatest activity in TASO extended over a period of 27 months, though some important activities were not completed for another nine months. The major product of TASO was a series of detailed engineering reports covering the work, the findings, and the conclusions of the panels and task forces. These reports, and other significant work of TASO, were summarized in a 731-page book, the over-all TASO report, entitled "Engineering Aspects of Television Allocations." The first copy of this report was presented to Chairman Doerfer of the FCC on March 16, 1959, and printed copies became generally available on June 12, 1959.

Summary of General Accomplishments of TASO

The following papers in this group of TASO papers give details of major engineering accomplishments of the organization. The remainder of this paper will be devoted to a summary of the more significant results of a general nature. First, however, the boundaries of the activities of TASO will be noted.

TASO did not undertake any cooperative equipment development or research. Prior to the establishment of TASO, the FCC stated its wish for a crash, all-industry, joint development program of UHF equipment. The television industry rejected this proposal as impracticable, in part because of patent considerations and antitrust laws. TASO's equipment studies were confined to equipment presently available commercially. Predictions of the nature of future equipment were not undertaken nor, in fact, even considered by the panels. This limitation in the scope of activity was made necessary by interpretations of the antitrust laws which prohibit joint activities by competing companies which might be considered to constitute lack of individual freedom in future designs or prices. It was, in fact, necessary for TASO to obtain assurance from the Department of Justice that its activities, within the scope of its charter, were not illegal before the work of the panels could proceed.

TASO did not undertake the preparation of an allocations plan. Such a plan is obviously dependent upon other considerations, in addition to engineering factors. TASO limited its activities to a consideration of engineering factors only. These should be basic to any allocations plan; but the preparation of such a plan is the responsibility of the FCC. It might be noted parenthetically that the decision to concentrate on engineering problems only, and to determine authoritatively the engineering facts, was probably the principal reason that the organizations sponsoring TASO, with their diverse and sometimes conflicting interests, could join in such an industry-wide endeavor.

Field Strength Measurements and Analysis

Turning now to technical accomplishments, one of the most significant was the collection and analysis of a large body of reliable data on the propagation of UHF and VHF signals within the service range of television stations. TASO was, of course, far from the first to collect this type of information. Prior to the TASO operations, however, relatively little data had been taken in the UHF television band; and at both UHF and VHF, measurements had been made in such a wide variety of manners that the results of different studies could not properly be compared. One of TASO's first tasks, therefore, was to draw up acceptable specifications whereby measurements of field strength would be made in a standard manner. These specifications were followed in all of the TASO studies of signal propagation within the service area.

Extensive field strength surveys were conducted at Baton Rouge, La., Buffalo, N. Y., Columbia, S. C., Fresno, Calif., Madison, Wis., New Orleans, La., Philadelphia, Pa., and Wilkes-Barre, Pa. Additional data taken at Albany, N. Y., Boston, Mass., Charlotte, N. C., Dallas, Tex., and Indianapolis, Ind., were made available to TASO. The areas chosen for the TASO surveys were selected because both UHF and VHF stations of comparable power output and quite closely adjacent transmitting antennas of comparable heights were available as signal sources. In addition, a wide variety of topographic and climatic conditions were represented. This field strength measurement program provided an excellent set of reliable data.

The analysis of the field strength data resulted in the development of improved means for predicting field strength. These included the preparation of propagation curves, essentially relating median field strength and distance from the transmitter, and the development of means for estimating with reasonable accuracy local deviations from these median curves. Pertinent factors involved in these latter calculations include meteorological conditions, path topography, and forestation in the vicinity of the receiving antenna. The development of the prediction means was based on both theoretical analysis and empirical studies of field-strength data. The recommended curves of median field strength as a function of distance are the theoretical smooth earth curves, using an effective radius of the earth appropriate to existing meteorological conditions, and with empirically determined correction factors of −1 db in the low VHF band, −4 db in the upper VHF band, and −22 db in the UHF band.

Frequency is obviously a most significant parameter in propagation studies, and is of major interest in allocation studies. Many measurements were made in such a manner as to permit a direct comparison between UHF and VHF fields. Generalizations drawn from such comparisons are fraught with danger, since such pertinent factors as transmitting-antenna height and location, exact path profile, and exact time of measurement are never entirely the same. Nevertheless, the results of some such comparisons will be given as an indication of trends.

The quantities compared are median values of UHF and VHF field strength taken from continuous runs at least 100 feet in length, at a receiving antenna height of 30 feet. Comparisons are also made between the variation in UHF and VHF field strengths along such runs. The results obtained from 1232 pairs of such runs (one at UHF, the other at VHF) along 60 radials in eight geographical areas across the country are shown in Figs. 2 and 3, in which the data from all comparisons in any one area are averaged and represented by one point. In Fig. 2, the ratio of the VHF to the UHF field strength per kilowatt of effective radiated power is shown as a function of carrier frequency f and transmitting-antenna height h, these two quantities being combined as the ratio $h_v f_u^{1/2}/h_u f_v^{1/2}$, the subscripts u and v designating UHF and VHF respectively. Except for Wilkes-Barre, where the terrain is exceptionally rugged, and New Orleans, where there was some question as to whether the power of the UHF transmitter was actually as high as reported, the data can be represented reasonably well by a straight line. In Fig. 3, the average ratio D of the maximum to the minimum field strengths, measured along the single continuous runs in the same eight geographical areas, is plotted as a function of the square root of the carrier frequency. Again, a straight line represents most of the data reasonably well. The points taken at Wilkes-Barre are again high. Here, runs of 500 feet were taken, thus making it more probable that deep nulls would be encountered than in the 100-foot runs taken elsewhere. The values of D obtained from the Wilkes-Barre data would thus be expected to be high. Part of the area around

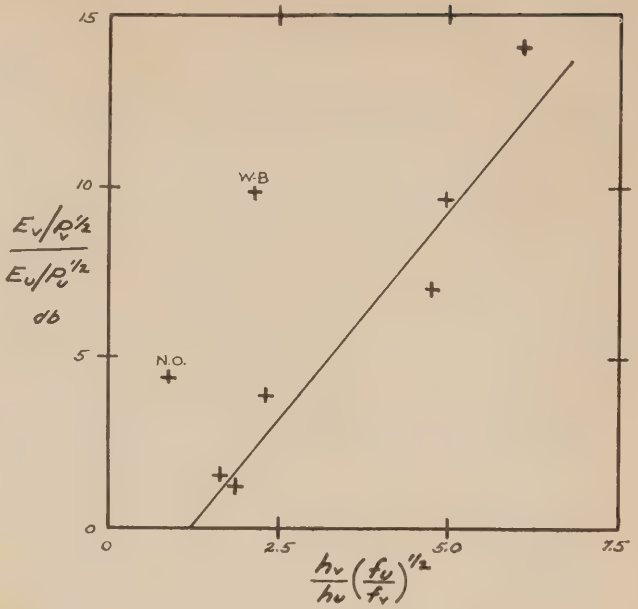

Fig. 2—Average ratio of VHF to UHF field strength per kilowatt of effective radiated power as a function of carrier frequency and transmitting antenna height.

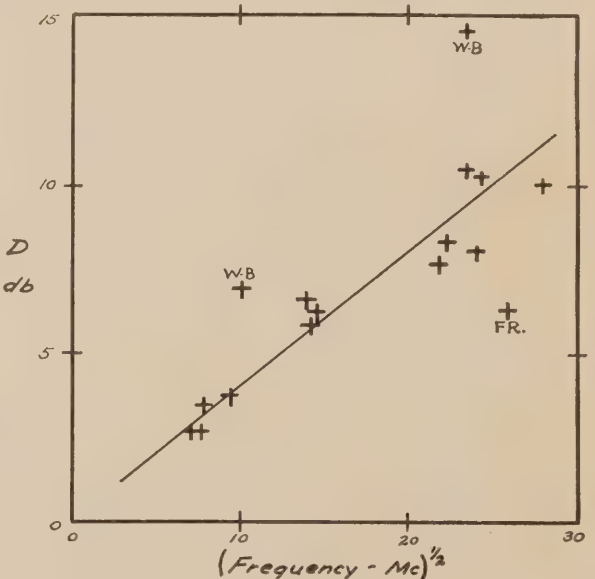

Fig. 3—Average ratio of maximum to minimum field strength along short paths as a function of carrier frequency.

Fresno was exceedingly flat and quite treeless, resulting in a low value of D. It is not suggested that Figs. 2 and 3 would give valid results if applied to other specific locations. The plotted points do, however, represent accurately the data which were taken, and the curves indicate the trends shown by the data which were taken in areas of average terrain and vegetation. In rough areas, the advantage of VHF over UHF is greater than indicated by the curve of Fig. 2. In flat, unvegetated areas, UHF shows to a greater advantage. In fact, in such areas and within line-of-sight distances, UHF field strength is frequently higher than VHF field strength for equal effective radiated powers and transmitting-antenna heights.

The significance of local conditions on received field strength is so important that it is worthwhile to give a few illustrations. A most striking case was that of a radial at New Orleans which ran northward across the 22-mile long Lake Pontchartrain bridge. Along the flat unobstructed path across the bridge, the UHF (507.25 mc) field strength averaged 8.1 db higher than the VHF (205.25 mc) field strength. Immediately to the north of the bridge, however, the UHF field strength dropped suddenly, and over the next 20 miles to the north it averaged 11.6 db lower than the VHF field strength. Another striking case occurred on a radial running southward from the Fresno transmitters, which are located on mountain tops overlooking Fresno and the San Joaquin Valley. In the foothills and rolling country near the stations, the VHF (209.75 mc) field strength averaged 5.2 db higher than the UHF (669.25 mc) field strength. Along the next 80 miles across the flat, almost treeless valley, the UHF field strength averaged higher by 9.2 db. As soon as the rolling country approaching the foothills on the far side of the valley was reached, the UHF field strength dropped to an average of 6.2 db below the VHF field strength. Because of the extremely high location of the transmitting antennas, essentially the entire length of this radial was within line-of-sight from both transmitters. With terrain which approached ideal, line-of-sight, flat, unobstructed conditions, the fields varied with frequency in accord with the smooth-earth theory of wave propagation, but under less ideal conditions, UHF performance deteriorated rapidly. Over-all, throughout the eight geographical regions covered by the TASO measurements, UHF field strength averaged 7.5 db lower than low-band VHF field strength and 4.5 db lower than high-band VHF field strength, all on the basis of equal effective radiated power. All but one set of UHF measurements were made in the lower half of the UHF television band.

It should be noted that these comparisons of field strength are valid only for limited distances, specifically for the distance at which UHF field strength could be measured. Beyond these distances, no quantitative comparisons could be made. If such comparisons could have been made, the average difference between VHF and UHF fields would have been much greater.

Field Tests of Television Reception

A second major technical accomplishment was the extensive program of field observations in which picture quality, as judged in typical homes by both technical observers and householders, was compared with field strength measurements made concurrently in the same areas. These field observations were made at varying distances from television transmitters out to the fringes of service areas. Thus, they took into account the fact that television receiving installations are not all the same, but increase in quality with distance from the transmitter, to compensate, more or less, for the decreasing field strength out to a distance where satisfactory reception becomes economically impractical. This "negative feedback" factor had been partially recognized before, but had not been evaluated quantitatively through consistently conducted observations under a variety of conditions.

The TASO field tests were made at Albany, N. Y., Bakersfield, Calif., Baton Rouge, La., Buffalo, N. Y., Columbia, S. C., Fresno, Calif., Harrisburg, Pa., Madison, Wis., and New Orleans, La., in the Connecticut Valley, and in Northern Minnesota. In all but two areas, which were chosen because of the availability of other necessary facilities, both UHF and VHF service existed. A wide variety of topography was represented in the eleven areas. In each geographical area, an average of nine measurement locations were chosen. In each of these, an average of eleven receivers were observed, and twelve field strength measurements of each principal television station were made. The homes in which observations were made were chosen in an unbiased, random manner. The television receiver was operated by the householder. The picture quality was rated independently by the householder and the two TASO observers, using a six-point rating scale. The field strength measurements were made in a manner consistent with that used in the propagation measurements.

The data taken in these field studies were classified and plotted in a variety of ways. The most fruitful methods of representing the data are shown in Figs. 4 and 5, which are typical of the many plots that were made. In Fig. 4, the ordinate is the median of the judgments of picture quality in the eleven or so homes in a single measurement location, while the abscissa is the median field strength at a height of 30 feet in the same measurement location. In Fig. 5, the ordinate is the same, but the abscissa is the distance from the transmitter to the measurement location. The final results of the analysis of these, and similar figures, are shown in Table I. The listed values of field strength which result in pictures of specified qualities are those chosen by Panel 3 after a thorough study by one of its committees of all of the data plotted in the manner of Fig. 4. The values of critical distance were obtained after a study of data plotted as in Fig. 5. The term critical distance requires some clarification. It is not a distance up to which excellent service exists and beyond which service

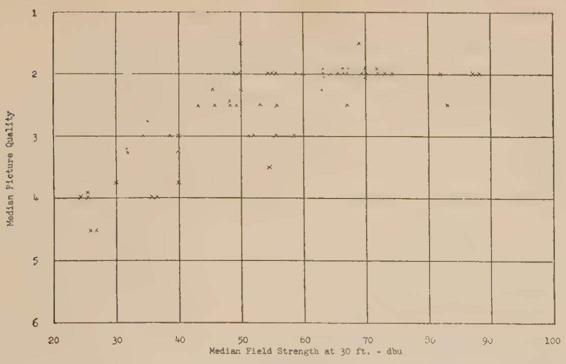

Fig. 4—Plot of median picture quality in a small area vs median field strength in that area for low VHF channels.

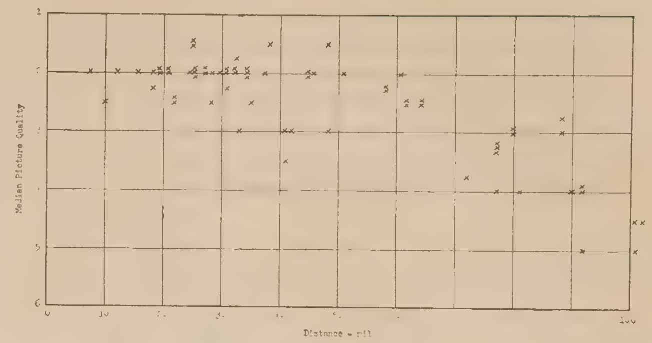

Fig. 5—Plot of median picture quality in a small area vs distance from transmitter for low VHF channels.

TABLE I

Frequency Range	Channel Range	Median Field Strength in DBU Resulting in Median Picture Quality of		Critical Distance (Miles)	Average ERP (kw)	Average Transmitting-Antenna Height* (Feet)
		Grade 2—Good	Grade 3—Passable			
Low VHF	2–6	50 and above	40–45	65	99	820
High VHF	7–13	60 and above	50–55	55	265	1010
Low UHF	14–40	65 and above	55–60	40	365	770
Middle and High UHF	41–83	72 and above	62–67	30		

* Above average terrain.

suddenly ceases. Rather, it is a distance up to which most residents can obtain reasonably adequate pictures [between passable (grade 3) and good (grade 2), and probably closer to passable than good] with economically practicable receiving installations. Beyond the critical distance, the percentage of viewers receiving adequate picture service decreases rather rapidly, while the percentage receiving poorer service increases correspondingly. Some persons beyond the critical distance will, of course, receive good service, while some within the critical distance will not. Moreover, in exceptionally favorable or unfavorable terrain, the critical distance will be appreciably greater or appreciably less than the values given. Speaking in broad, general terms, however, the TASO field surveys showed that, under average conditions, with currently used effective radiated powers and transmitting antenna heights, service fell off rapidly beyond the listed values of critical distances. The data in Table I show the average powers and antenna heights of the stations used in the surveys, and it should be noted that these values are quite typical of existing, well-operated stations.

The significance of the results given in Table I is that they were obtained by carefully designed and conducted field tests, using receiving installations as found in typical homes. No assumptions were made regarding such diverse factors as receiving antenna gain and height, condition of receiver lead-in, receiver sensitivity, receiver adjustment, transmission-path topography, obstructions in the vicinity of the receiving antenna, etc. Detailed analyses, which compare the results obtained in the field tests of television reception with those derived from the analysis of propagation data and from the laboratory studies of the performance of receiving equipment, are given in the TASO report. The results are not inconsistent, and in most cases, they are amazingly similar.

From Table I, the decrease in critical distance with increasing frequency is plainly evident. It is interesting to plot critical distance as a function of the mean carrier frequency of the stations observed. The results are shown in Fig. 6. The studies also showed that beyond the critical distance, UHF service fell off more rapidly and more completely than did VHF service. Within the critical distance, service was more variable at UHF than at VHF and was, on the average, poorer.

LABORATORY STUDIES OF TELEVISION PICTURE QUALITY

A third major project was a study of the relationship between subjective picture quality, as judged by representative groups of observers drawn from the general public, and technical picture impairment due to controlled additions of interferences of different types and amounts. A comprehensive series of laboratory tests was conducted by TASO to determine the statistical relationship between picture quality, as rated on the six-point scale, and desired-to-undesired signal ratio, using for the undesired signal thermal noise, cochannel interference (with normal, precise and very precise carrier frequency offset), and adjacent-channel interference (upper and lower), as well as certain combinations

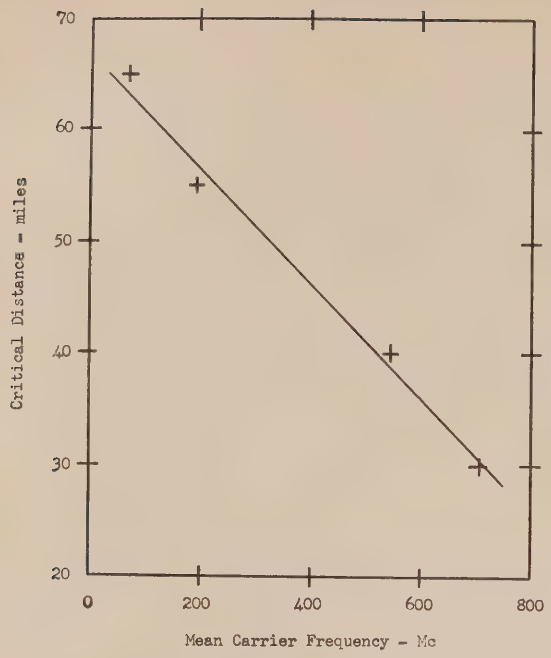

Fig. 6—Plot of critical distance, beyond which average service deteriorates rather rapidly, vs carrier frequency.

of these types of interference. Observations were made using both color and monochrome receivers judged to be of type and quality representative of upper middle grade receivers. These tests were conducted by TASO panel members skilled in the design, conduct, and interpretation of psychological tests, as well as by those skilled in television engineering. A variety of still pictures were used for the desired and interfering television signals. Tests were made to determine the effects of different pictures and groups of observers, and to check the self-consistency of observations. These checks showed a satisfactory degree of reliability of the results which were obtained.

It is difficult to summarize briefly the large amount of data which were taken. Representative values of interference resulting in a passable (grade 3) picture are given in Table II. The tests of combined thermal noise and cochannel interference showed that the greater interference predominated until the two levels of interference were within a few decibels of each other. In some cases, the presence of thermal noise appeared to lessen the disturbing effects of cochannel interference.

TABLE II

Type of Interference	Average Ratio of Desired-to-Undesired Signal (DB) Required for a Passable Picture
Thermal noise	27
Co-channel, 360-cycle carrier offset	22
Co-channel, 604-cycle carrier offset	41
Co-channel, 9985-cycle carrier offset	22
Co-channel, 10,010-cycle carrier offset	18
Co-channel, 19,995-cycle carrier offset	26
Co-channel, 20,020-cycle carrier offset	18
Lower adjacent channel	−26*
Upper adjacent channel	−27

* This value must be used with caution, as it depends upon the lower adjacent channel trapping in the receiver and upon the signal level. The trapping in the average receiver now in use in the home will not permit as high a level of lower adjacent channel interference as indicated here. A value of perhaps −10 db to 15 db rather than −26 db might be more representative of results obtained with average receivers currently in the hands of the public.

TROPOSPHERIC PROPAGATION CURVES

Allocation studies require not only a knowledge of the propagation of desired signals within the service range of a television station, but also information regarding the propagation of interfering signals from stations located at distances much greater than their service ranges. The results of more than a million hours of measurements of distant signals made by the Central Radio Propagation Laboratory of the National Bureau of Standards were made available to TASO, and curves representing the best current information on tropospheric propagation of UHF and VHF signals over distances of between 100 and 300 miles were prepared from these and other data. Generally speaking, for comparable conditions, UHF interfering fields were shown to be lower than VHF interfering fields, but the difference is not as great as in the case of service fields.

EQUIPMENT PERFORMANCE

A final major accomplishment of TASO was the critical evaluation of the performance of modern UHF and VHF television transmitting and receiving equipment. Of the two, receiving equipment is of greater significance as a limiting factor in the operation of a television system.

The work on receiving equipment included the collection of data on the gain (and other characteristics) of receiving antennas, the loss in transmission lines, the noise factor and sensitivity (and other characteristics) of receivers, and the performance of vacuum tubes and other electron devices used in television tuners. Incidentally, before data on the performance of receivers could be gathered, it was necessary to draw up specifications for standard methods of measuring the characteristics of modern television receivers, as existing standards were seriously out of date. A consideration of the various factors as combined in a receiving system led to conclusions regarding the basic limitations of receiving equipment at the various frequencies employed in television broadcasting. The general conclusions were that, with presently available equipment of average quality, a high-band VHF signal must be 8.1 db higher than a low-band VHF signal to produce the same signal-to-noise ratio, and that a UHF signal must be 23.2 db higher than the low-band VHF signal. These figures were based on the use of new, dry transmission line. If old, wet line is used, the corresponding figures are 9.3 and 26.9 db, respectively. In the field and within the service range of a transmitter, these differences may be partially (but only partially) compensated in any given area by a factor previously noted, that the viewer will purchase as good a receiving installation as is necessary to receive adequate pictures out to the limit of service. The limiting differences in receiver performance quoted above do, of course, enter very directly into the determination of the limit of the service area.

The studies of transmitting equipment included a consideration of economic as well as technical factors. The TASO activities were directed toward studies of the characteristics, performance, reliability, and cost of currently available transmitters; the characteristics and cost of antennas, towers, and transmission lines; the performance of translators; and the applicability of new techniques in the operation of transmitting equipment. In very brief summary, the cost of a complete, maximum-power (316 kw) high-band VHF transmitting installation was found to average about 25 per cent higher than that of a complete, maximum power (100 kw) low-band VHF installation. UHF installations operating at powers up through 300-kw effective radiated power were shown to cost, on the average, about 10 per cent less than maximum-power low-band VHF stations. Little information was obtained regarding 500- and 1000-kw UHF stations, but it appeared that their cost was comparable to that of maximum-power low-band VHF stations. UHF translators appeared to be effective in providing television service in areas remote from regular broadcasting stations and in "filling in" areas of low signal strength within the "normal" service range of television transmitters.

A major task of special significance was the thorough testing of high-power, directional television transmitting antennas under field conditions at WBZ-TV, Boston, Mass., and WKY-TV, Oklahoma City, Okla. The WBZ-TV installation involved the modification of an existing antenna, while at WKY-TV a specially designed antenna was installed and tested. The WKY-TV installation included means for rotating the complete transmitting antenna, as well as the provision of an auxiliary, rotatable, reference antenna. These tests not only gave reliable information regarding two specific directional antenna installations under field conditions, but also served to demonstrate the validity of procedures developed by TASO for conducting reliable performance tests of directional transmitting antennas. These tests indicate that satisfactory performance could be obtained with supression ratios as great as 15 db.

INTERFERENCE

A factor which favors UHF operation is that of greater freedom from interference. Although TASO did not make quantitative measurements of interference, the observations made in the field surveys of television reception, the results of a questionnaire survey of television servicemen, and the results of inquiries directed to service managers of leading television receiver manufacturers showed clearly that UHF television is substantially free from atmospheric interference, from such man-made interference as ignition and other impulsive electrical noise, and from airplane flutter. Multipath difficulties were not found to be a really serious factor except in large cities. In most locations where it existed, multipath was more objectionable at VHF than at UHF. Galactic, or cosmic, noise, which may be a bothersome source of interference in fringe areas in the low VHF band, is of no consequence at UHF. Finally, although there were frequent reports of co-channel and adjacent-channel interference at VHF, there were practically no such reports at UHF. This, however, may well be due at least in part to the relatively small number of UHF stations on the air to cause such interference, since the curves of interfering (or tropospherically propagated) field strength developed by TASO indicate that, at equal distances and for comparable effective radiated powers and transmitting-antenna heights, interfering field strengths at UHF are only some 6 db lower than at VHF.

UHF VS VHF OPERATION

The preceding discussion indicates several significant factors affecting the difference in performance of a television system at UHF and VHF. Some of these factors are truly basic in their nature, and are not susceptible to complete compensation by the application of known techniques. Others stem from equipment limitations which may or may not change as the art progresses. The most significant differences between UHF and VHF performance are due to propagation effects, receiving-antenna characteristics, receiver noise factor, and external noise. The first three factors favor VHF, while the fourth favors UHF. Propagation effects depend upon laws of nature, and the differences between UHF and VHF propagation are likely always to exist. Differences between UHF and VHF receiving antennas are due to both basic and equipment limitations. Future inventions may reduce, but not erase, these differences. Improvement in the noise factor of UHF receivers is to a considerable extent a matter of economics, and is almost certain to occur. The present limitation is the lack of a good economical radio-frequency amplifier tube or other electron device. The noise factor of VHF receivers will probably also be improved; but in the long run the advantage of VHF receivers over UHF receivers with respect to noise factor will probably be reduced. The lower external noise at UHF is largely a basic factor, and probably will not change greatly. Over-all, it appears that while future developments will probably reduce the difference between UHF and VHF television performance, VHF television will continue to enjoy a substantial advantage.

SIGNIFICANCE OF THE WORK OF TASO

The significance of the work of TASO is difficult to evaluate at this time. TASO has presented to the FCC a very large amount of reliable information regarding engineering factors which should be taken into consideration in arriving at decisions regarding television allocations. It seems that such decisions should be better because of the work of TASO.

The Measurement of Television Field Strengths in the VHF and UHF Bands*

H. T. HEAD† AND O. L. PRESTHOLDT‡

Summary—**The effective and intelligent administration of television broadcast channel allocations requires acceptably accurate estimates of field strengths which will be produced by television broadcast stations. Propagation curves and prediction methods in use at the time of the founding of TASO were in many respects inadequate. Insufficient data were available for the preparation of new propagation curves; a new standard measuring specification was prepared, and an extensive program of field strength measurements was undertaken.**

This paper discusses the details of the TASO field strength measuring specification and describes the program of field strength measurements. A summary of the results of the measurements is presented.

INTRODUCTION

ONE of the principal engineering requirements in formulating plans for the allocation of television channels is that of estimating the service ranges of television stations. This requires a determination of the field strengths of both desired and undesired signals within the service areas. Previous methods of predicting field strengths have taken into account the effects of frequency, power, and antenna height, but have not provided means for assessing the influence of topographic and other conditions.

Historically, field strength prediction was first dealt with by employing classical curves of field strength vs distance derived on the assumptions of a smooth spherical earth and a homogeneous standard atmosphere.[1] Increasing experience, however, indicated that deviations from these classical propagation path assumptions all too frequently resulted in field strengths markedly different from those predicted.

The field strength measurement data available at the time of the formation of TASO were inadequate to provide the needed improvement in the tools and techniques for estimating field strengths within the service ranges. There was a particular paucity of measured field strength data at the ultrahigh frequencies, and much of the information available at both the ultrahigh and the very high frequencies had been accumulated by such a wide variety of means as to greatly reduce its value for this purpose.

The Ad Hoc Committee of 1948 had reviewed the field strength measurement data available at that time (principally at VHF) and prepared new empirical curves of VHF field strength vs distance as a function of antenna height.[2] Separate families of curves were prepared for 63 mc and 195 mc, but the available data did not permit taking into account many important influences, such as terrain roughness, and the curves were applied uniformly on an average basis throughout the entire United States. The UHF measurements available at that time were extremely meager, but indicated generally that the average UHF field strengths out to a distance of about 20 miles from the antenna were approximately the same as those found at 63 mc.

The Federal Communications Commission adopted the curves prepared by the Ad Hoc Committee at 63 mc and 195 mc and, for the lack of any better data, applied the 63-mc curves throughout the UHF band (470–890 mc).[3] Subsequent experience indicated that the UHF service curves were seriously in error in many situations,[4] but little additional measurement data became available at the UHF. A need for substantial additional information at both VHF and UHF was apparent.

Faced with this need for additional field strength data within the service ranges of television stations, TASO assigned to Panel 4 the task of collecting the data needed to provide more adequate information on VHF and UHF propagation characteristics and to support a sound approach to the propagation problems involved. It was apparent that an extensive field strength measuring program was essential to fill important gaps in existing knowledge. Data were needed to permit the derivation of improved average curves of field strength vs distance, and to assist in the evaluation of the effect of terrain roughness on these curves. It was hoped that the results would lead to the development of methods for improved predictions of field strengths in small areas.

TECHNICAL PROBLEM

The measurement of field strengths in the frequency bands employed for television broadcasting is not a simple problem. The fields may vary widely from one location to another, even within small areas, and at

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* Original manuscript received by the IRE, February 18, 1960.

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[1] K. A. Norton, "The calculation of ground-wave field intensity over a finitely conducting spherical earth," PROC. IRE, vol. 29, pp. 623–639; December, 1941.

[2] Ad Hoc Committee for the Evaluation of the Radio Propagation Factors Concerning the Television and Frequency Modulation Broadcast Service in the Frequency Range Between 50 and 250 mc, FCC Rept. No. 36830, vol. I; May 31, 1949.

[3] "Sixth Report and Order," FCC Rept. No. 52-294, 74219, docket nos. 8736, 8975, 9175, 8976, Paragraph 89; April 14, 1952.

[4] E. W. Chapin, "UHF field intensity measurement experience," IRE TRANS. ON BROADCAST TRANSMISSION SYSTEMS, no. PGBTS-3, pp. 32–38; January, 1956.

greater distances may also vary appreciably with the passage of time. The classical prediction of a linear increase in field with receiving antenna height is rarely realized in practice.[5] Many other influences, often largely unknown, may affect the strength of the received signals.

As a consequence of these variable influences, field strength measurement surveys made by different methods have often been found to yield substantially different data. Frequently, surveys made on the same transmitter are not directly comparable because of differences in the measuring techniques. A method of making field strength measurements in these frequency bands is detailed in the Federal Communications Commission's Technical Standards,[6] but experience has shown that this method is not necessarily the most suitable for the collection of data for propagation analysis purposes. In addition, this method suffers from various shortcomings, even when applied for its originally intended purpose of establishing the coverage areas of operating television and FM stations.

MEASURING STANDARDS

The Commission's Radio Propagation Advisory Committee (RPAC) has established the following requirements for field strength measurements on television stations.

1) They should indicate whether or not the transmitter and antenna system are performing in the manner predicted in the application for the facility.

2) They should determine the extent and quality of service rendered by the operation, showing the areas not getting satisfactory service as well as those getting good service.

3) At least some of the measurements should be suitable for technical studies and should add to the general knowledge of propagation conditions in the frequency bands involved.

4) The measurements should be reasonably reproducible, so that they may be checked at a future date if desired.

5) The techniques for making these measurements should not be too impractical or expensive.

Prior to the formation of TASO, however, no definite measuring specifications meeting these requirements had been drawn up, and many workers employing various techniques had accumulated data which were difficult or impossible to correlate. Under these circumstances, TASO Panel 4 was, therefore, faced with the initial problem of standardizing on a measuring technique. This required the establishment of measuring specifications which would provide uniform data suitable for analysis by various methods,[7] and measurements so taken as to provide an insight into propagation mechanisms.

TASO Committee 4.1 divided the measuring specification problem into two parts—techniques for collecting data for analysis purposes, and methods of measuring the service areas of operating stations. Agreement was reached on techniques for making measurements to be used primarily for propagation analysis. The establishment of techniques to measure service areas of television stations is a controversial problem and TASO did not reach unanimous agreement for the adoption of any technique.

TASO MEASURING SPECIFICATION FOR PROPAGATION ANALYSIS

The process of establishing the measuring specifications required a substantial amount of exploratory measurement work in the field. This initial work included several series of continuous mobile measurements in varying types of terrain at both 10- and 30-foot receiving antenna heights over complete radial routes. These data indicated that the antenna height-gain relationship was extremely variable and depended on factors which could not be accurately evaluated. An analysis of these data also demonstrated that suitable sampling techniques would provide adequate data.

Because of the variability of the height-gain function, it was felt desirable to make the field strength measurements at a receiving antenna height of 30 feet above ground, which is the standard for allocation purposes. Continuous mobile measurements at this receiving antenna height would involve prohibitive labor, but the results of the sampling analysis had established the acceptability of a sampling technique, such as a short mobile run or a "cluster" of spot measurements.

Since the received fields are a function of the characteristics of the propagation path, it is desirable to make measurements in a radial pattern from the transmitting antenna. However, a random selection of measuring locations is desirable to provide a representative selection of receiving sites; also, successive measurements should be sufficiently separated to minimize the effects of serial correlation.

A consideration of the problems presented led to the ultimate preparation of a specification for the "Measurement of Television Field Strengths in the VHF and UHF Bands," which is included in the final report of TASO to the Commission. Copies of the final specification, which describes the recommended measuring process in detail, are available from Dr. George R. Town, Dean of Engineering, Iowa State University, Ames, Iowa. The principal features of this specification will be briefly described.

The specification provides for measurements along eight or more approximately equally spaced radial routes from the transmitter to be laid out on large scale topographic maps. The routes should be chosen so as to encounter representative samples of the terrain. Starting at ten miles from the transmitter, exact two-mile intervals are laid out along each radial. The measuring location is specified as the intersection of the radial and an accessible road nearest to each of the two-mile markers. If such a measuring location is not available, a substitute location suitably identified should be selected along the road nearest the appropriate mileage marker and as nearly as possible at the same elevation as the mileage marker.

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[5] H. T. Head, "Measurement of television field strength," *Elec. Engrg.*, vol. 77, pp. 289–302; April, 1958.

[6] Rules and Regulations of the FCC, Television Technical Standards, Part 3, §3,686.

[7] A. H. LaGrone, "Forecasting television service fields," this issue, p. 1009.

Ordinarily, the radial lines are laid out on the topographic maps using ordinary drafting methods, exercising care to produce a great circle track as accurately as possible. For certain types of analysis, some workers in the propagation analysis field require that the radial lines be more precisely established. A method of laying out the radials by calculation is appended to the measuring specification and was used in laying out the measuring routes for some of the later surveys.

The measurements made at each location consist of continuous recordings for a distance of approximately 100 feet along the road with the receiving antenna at a height of 30 feet above ground. The detailed procedure consists of the following routine at each measuring location. First, check the calibration of the instruments; second, elevate the receiving antenna to a height of 30 feed above ground; third, rotate the receiving antenna and determine whether the maximum signal is arriving from the direction of the transmitter. Next, with the chart recorder operating and the receiving antenna oriented toward the transmitter, record the field strength on the chart while making a run of 100 feet along the road, centered on the intersection of the radial route with the road. Mark the exact position of the measuring location on the topographic map, and in the notebook characterize in detail the topography, height and type of vegetation, habitation, obstacles, weather, and any other local features believed to have an influence on the received field. Identify the data by suitable numbering.

If overhead obstacles will not permit a run of 100 feet, a cluster of five spot measurements should be substituted. If at the beginning of a 100-foot mobile run the maximum signal appears to come from a direction other than that of the transmitter, the mobile run should be made with the antenna oriented toward the transmitter and a five point cluster should also be measured, making two observations at each point, one with the antenna oriented for maximum response and the other with the antenna oriented toward the transmitter.

Either visual or aural carrier may be measured; if the visual carrier is measured, a peak reading voltmeter must be employed to assure that the field strength observed corresponds to the synchronizing peak.

The TASO field strength measuring specification recognizes the considerable hazard involved in operating a moving vehicle with an erected 30-foot mast. An appendix to the specifications details suitable safety precautions to be observed in the operation of the measuring vehicle.

MEASURING METHODS FOR DETERMINING STATION COVERAGE

Field strength measurements to determine the coverage of an operating station present a different problem from that of collecting data for propagation analysis. Techniques best suited to the latter purpose may not provide adequate results for the preparation of coverage maps or may involve unnecessary labor.

TASO did not establish measuring specifications to determine station coverage. Recommendations were agreed upon for changes in the method now prescribed by the FCC Technical Standards, and a radically new method of measuring station coverage was recommended for field trials.

A. Recommended Modification of FCC Method

The method now prescribed by the FCC Technical Standards requires continuous mobile recordings along roads extending generally radially outward from the transmitting antenna. The routes are required to follow the cardinal and subcardinal points of the compass. The received fields (at a receiving antenna height on the order of 10 feet) are converted to those expected at the 30-foot antenna height by undefined means.

TASO recommended changes in the selection of measuring routes and the application of height-gain factors. It was recommended that the measuring routes be selected with engineering judgment, so as to encounter terrain representative of the sectors being sampled. The number and direction of the measuring routes should be chosen so that an interpolation between adjoining routes may be reasonably expected to represent propagation conditions actually obtaining. Height-gain factors as shown in Table I were recommended for the 10-foot to 30-foot conversion.

TABLE I
RECOMMENDED 10-FOOT TO 30-FOOT HEIGHT-GAIN FUNCTIONS

Channel	Smooth Unobstructed Terrain	Rolling Hilly Terrain	Rough Terrain
2– 6	9.5 db	8 db	7 db
7–13	9.5 db	7 db	5 db
14–83	9.5 db	5 db	2 db

B. Proposed Circular Arc Technique

The newly proposed technique is a radical departure from past practice and is based on a proposal by Kirby.[8] The following background information will be helpful in establishing a proper perspective for this technique.

Current knowledge of wave propagation indicates that statistical methods may be appropriately used in reporting VHF and UHF field strength behavior. A group of measurements taken by a uniform sampling technique, in a small area at a fixed distance from a transmitter, will in most types of terrain exhibit an appreciable variation from one location to another. TASO has referred to such small areas as "cells." A series of such groups of data at different distances from the transmitter over typical terrain will show a variation of the mean field strength with distance.

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[8] R. S. Kirby, "Measurement of service area for television broadcasting," IRE TRANS. ON BROADCAST TRANSMISSION SYSTEMS, no. PGBTS-7; pp. 23–30; February, 1957.

If such measurements are taken in groups along two different radials but over the same general kind of terrain, it will usually be found that the variation of mean field strength with distance is similar for the two radials and that the scatter of the data in individual groups is also similar. The distribution of field strengths in these groups, when measured in dbu,[9] is found to closely approximate a normal distribution. The range between the field strength exceeded at 50 per cent of the locations and that exceeded at 84 per cent of the locations (the standard deviation) is comparable to the variation of the mean itself with distance over a range of 5 to 15 miles, depending on frequency and terrain.

The mean field strengths vary with distance generally as shown by standard propagation curves such as those contained in the FCC Technical Standards. It has also been found that the terrain influences the mean widely, that the curve may be lowered or raised from the reference curve, and, equally important, that its slope or its shape may be altered materially. Experience has also shown that the standard deviation varies with frequency and terrain roughness. It is not known whether there is an important variation of this parameter with distance.

In the general case, neither of these field strength parameters can be deduced from the other. Thus both are important in determining the service from a broadcast station. To summarize, the field strength in a "cell" may be described in terms of a mean field strength and a standard deviation describing a normal statistical distribution.

The proposed new technique specifies that measurements be taken along a pattern of circular arcs rather than radial lines. The samples would be selected along a series of three to five uniformly spaced concentric circles about the transmitter. The radii of the circles would range from a distance approximating the principal city contour to that approximating the service limit of the station. A total sample of about 400 spot measurements would be used, with the division of measurements among circles approximately proportional to the square root of the circle radius. The measuring locations should be uniformly distributed over each circle. The measurements are to be single spot measurements taken at a receiving antenna height of 30 feet.

For a typical high-power VHF station, a pattern of five circles might be used with radii of approximately 20, 35, 50, 65 and 80 miles. The number of points per circle would be 52, 69, 82, 94 and 104, respectively. This suggested layout is shown in Fig. 1, and cells at distances of 20 and 65 miles are indicated.

In analyzing the data, the area around the station should be divided into eight or more sectors not exceeding 45° in width of reasonably homogeneous terrain. In smooth or gently rolling terrain, which is more or less uniform in all directions, these sectors could be at exact 45° intervals (starting, for example, with true north).

The spot measurements on each circle within each sector (each cell) would be considered an individual group of data for analysis purposes. The mean and standard deviation for each individual data group should be determined. From these data, curves of mean field strength vs distance for each of the sectors may be drawn. For percentages of locations other than 50 per cent, similar field strength vs distance curves may be drawn for each sector by reference to the specific data for each cell.

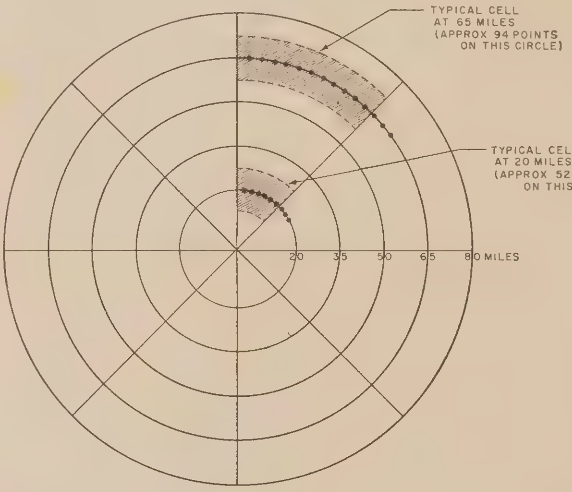
TYPICAL CELL AT 65 MILES (APPROX 94 POINTS ON THIS CIRCLE)
TYPICAL CELL AT 20 MILES (APPROX 52 POINTS ON THIS CIRCLE)
20
35
50
65
80 MILES

Fig. 1—Partial layout of measurement program for a typical maximum service VHF station.

C. Coverage Measurements in Cities

TASO considered that the usual application of the two techniques just described would not provide adequate data for determining coverage of cities. A separate specification for a measuring technique for this purpose was recommended by TASO without qualification.

Measurements to determine the coverage of cities should consist of single spot measurements at a receiving antenna height of 30 feet. The measuring pattern provided by the TASO specifications is a rectangular grid laid down on a map of the city. The measurements are to be taken at the intersections of the lines of the grid or as close to the intersections as is practical. The dimensions of the grid should be such that the total number of measurements is at least three times the square root of the population of the city taken in thousands.

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[9] DBU: a term coined by the FCC, signifying the field strength in decibels above 1 μv/meter.

These spot measurements are to be analyzed as a single group. The mean and the standard deviation should be determined either by computation or by ordering and plotting the data on probability graph paper, expressing the field strength in dbu. From this analysis, a determination may be made as to the percentage of locations in the city which receive a field strength equal to or greater than any specified value.

MEASUREMENT PROGRAM

Concurrently with the drafting of the field strength measuring specifications, a program of actual field strength measurements was begun. The objective of the measuring program was the collection of field strength measurement data in substantial accord with the measuring specifications, representing propagation over as wide a range of frequencies, antenna heights, terrain and other conditions as practical. Obviously, it was not feasible to investigate and measure transmitters operating under all combinations of conditions. However, the selection of areas under the guidance of TASO Panel 4 was such as to provide a reasonably representative sampling of many important combinations of the various influences.

In selecting the areas where the measurement surveys were to be conducted, an attempt was made wherever possible to choose situations where both VHF and UHF signals could be measured simultaneously and, where possible, from transmitting antennas in close proximity to each other. Table II lists the areas in which complete surveys were made in accordance with the field strength measuring specification, giving the frequencies of the transmissions and the average effective antenna heights above the terrain between 2 and 10 miles from the transmitting antenna.

TABLE II
TASO FIELD STRENGTH SURVEYS

Location	Frequency in mc	Average Effective Antenna Height in feet
Wilkes-Barre, Pa.	98.5	1160
	559.75	1220
Philadelphia, Pa.	90.9	463
	601.74	503
Madison, Wis.	61.25	795
	585.26	690
Fresno, Calif.	209.75	2000
	669.25	1787
Columbia, S. C.	193.24	640
	789.26	624
Springfield, Mass.	93.1	968
	631.75	1000
Baton Rouge, La.	59.75	890
	559.75	490
Buffalo, N. Y.	59.75	380
	493.75	686

In addition to the complete surveys listed in the table, a limited number of measurements were made on VHF transmissions in the Boston, Mass., area and UHF transmissions in the Albany, N. Y., area. However, the measurements tabulated constituted the bulk of the data taken specifically for TASO purposes.

1) *Equipment:* The TASO equipment specification requires the use of a field strength meter of professional quality and prescribes that the measurements be made at a receiving antenna height of 30 feet above ground. These requirements dictate the use of an automobile or light truck for transporting the equipment.[10] This vehicle is additionally equipped with a chart recorder so arranged as to provide chart motion approximately proportional to vehicle motion.

Fig. 2 is a photograph of one of the mobile units equipped for these measuring surveys, showing the hydraulic mast in the retracted position for traveling. The same unit is shown with the mast extended in Fig. 3,

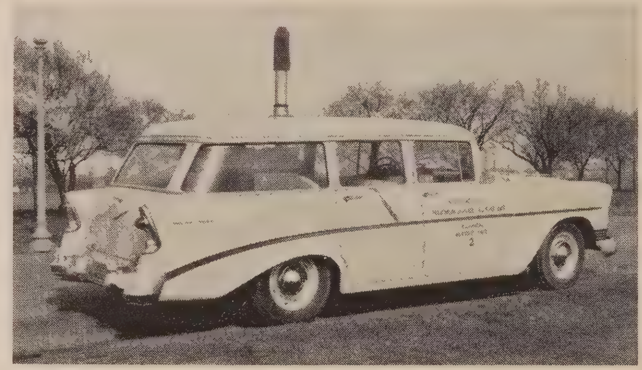
Fig. 2—Mobile field strength survey unit equipped for TASO surveys (photographs courtesy Association of Maximum Service Telecasters, Inc.).

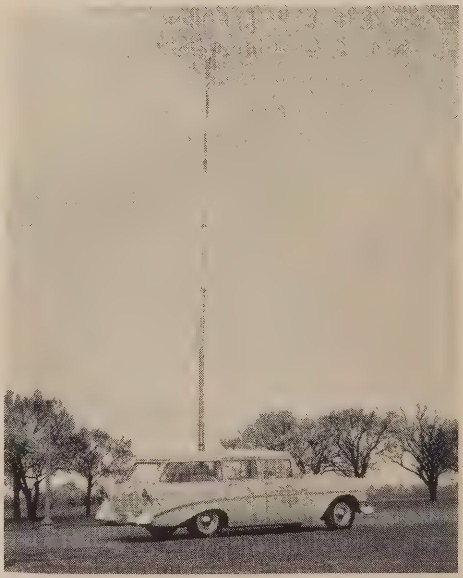
Fig. 3—Mobile unit with hydraulic mast extended to 30-foot height.

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[10] "NAB Engineering Handbook," 5th Ed., Sect. 2, Pt. 8, McGraw-Hill Book Co., Inc., New York, N. Y.; 1960.

which also shows a UHF receiving antenna mounted on top of the mast. The mast supports the receiving antennas at the 30-foot height while the vehicle is in motion and is rotatable.

Fig. 4 is an interior view of the mobile unit, showing the mounting of the UHF and VHF field strength meters. Two Esterline-Angus chart recorders, one for each field strength meter, were mounted on a platform in the front seat of the vehicle and were driven by means of a connection to the speedometer cable. Fig. 5 shows the mounting of the chart recorders.

The TASO field strength measuring specification prescribes the antennas to be employed for making the surveys. For UHF measurements, the antenna employed should have directivity in the horizontal plane and exhibit a single main lobe over the appropriate frequency range. The antenna should have a gain of 6 to 10 db with respect to a half-wave dipole. For VHF, a half-wave or shorter dipole should be employed. In areas where VHF signals may be contaminated by interfering fields, directional antennas may be employed.

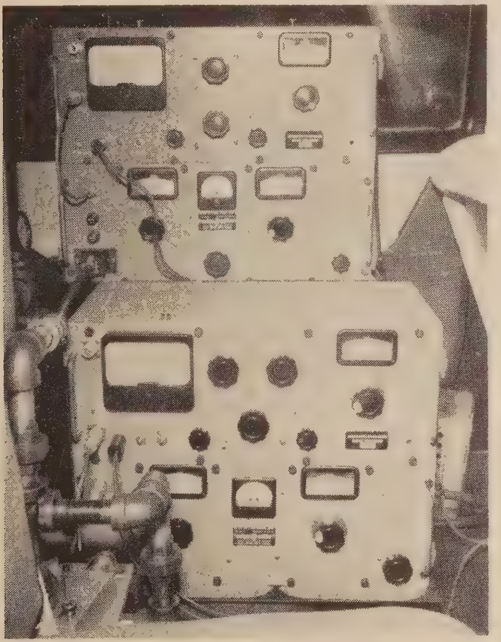

Fig. 4—UHF and VHF field strength meters in operation in mobile unit.

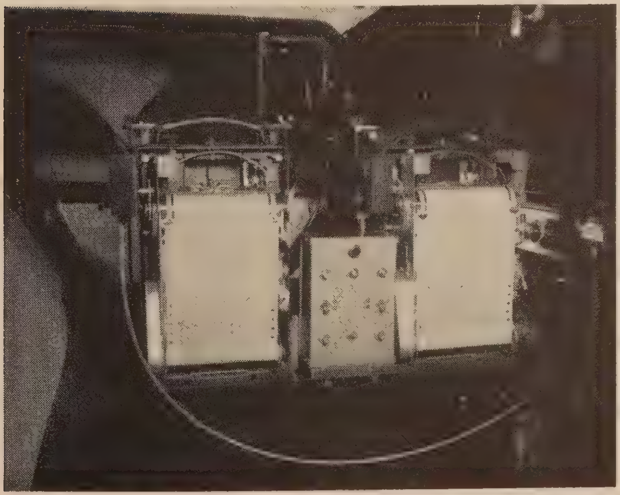

Fig. 5—Chart recorders for mobile unit.

In establishing the specifications for the receiving antennas, it was recognized that high-gain UHF antennas may not develop their free space gain in some areas, especially in rugged terrain. In situations where this is true and field strength data are gathered with a dipole receiving antenna, estimates of service available to installations using high-gain antennas in such areas will be optimistic. By gathering field strength data with a receiving antenna having characteristics approximating those of a typical home antenna, the errors in estimating the voltage delivered to the receiver input terminals are largely self-canceling. Additionally, available UHF field strength meters are not sufficiently sensitive to measure very weak signals without the use of receiving antenna gains. These considerations established the basis for the UHF antenna specifications. For measurements in the VHF range, the arguments are different. VHF field strength meters will measure to a sufficiently low signal level without antenna gain, experience has shown that the loss of antenna gain is less likely to occur on VHF, and the physical size of a high-gain antenna becomes excessive on the lowest VHF channels. It was, therefore, decided that the VHF standard antenna would be a half wavelength or shorter dipole, with the proviso that in areas subject to interfering fields, directional antennas might be employed.

The TASO equipment specification provides for the use of a shielded transmission line between the antenna and field strength meter. The antenna impedance should be matched to the transmission line and, if an unbalanced line is used, a suitable balun is to be employed to join the balanced antenna to the transmission line.

The use of a receiving antenna other than the standard dipole requires the determination of the gain of the measuring antenna relative to the dipole. This calibration should be made in a clear level area at least 10 miles from the transmitter and in an area where the signal is quite uniform, a variation of 1 db or less being considered adequate. The area must permit a mobile run of 100 to 500 feet with the mast erected. At least three runs should be made over the calibration route with each antenna. In addition to establishing the antenna gain, the horizontal pattern of the antenna should be measured by rotating the antenna through a full 360° and observing relative field strength at 10° intervals.

The measuring equipment employed in making the field strength surveys listed in Table II was calibrated against laboratory standards at periodic intervals. In addition, a calibration program of all the equipment employed was undertaken by the Electrical Engineering Department of Iowa State University, Ames, Iowa. This calibration program assured that any instrumental errors which might be introduced into the data were on the order of something less than 1 db.

2) *Reporting of Results:* The TASO measuring specification recommends the data to be included in reporting the field strength measurements. Tables should be included of the measured field strengths in each direction from the transmitting antenna, giving the distance from the antenna, the ground elevation at the measuring location, the median, minimum and maximum field strengths for each 100-foot mobile run reduced to dbu for 1 kw radiated, and any pertinent notes. Fig. 6 is a sample of a portion of one of these tables listing this information and, in addition, giving additional data for continuous mobile measurements at a 10-foot receiving antenna height.

The report of the measurements should also include large scale topographic maps showing the exact locations at which the measurements were made. In addition, a detailed description of each transmitting installation, a list of the calibrated measuring equipment used, and a detailed description of the calibration should be supplied. It is also recommended that terrain profile graphs be prepared for each direction in which measurements are made, drawn on "curved earth" graph paper for an equivalent four-thirds earth's radius. The reports which were supplied to TASO included these terrain profile graphs for each radial route and, in addition, included graphs of measured field strength vs distance plotted directly above the terrain profile graphs. Figs. 7 through 10 are sample graphs showing the terrain profiles and plots of field strength vs distance for several representative measuring runs. Fig. 7 shows measurements of a VHF signal over smooth terrain. Fig. 8 shows measurements on a UHF transmitter over essentially the same path. Figs. 9 and 10 are similar measurements over a path in very rugged terrain.

The dashed lines on Figs. 7 through 10 show the predicted fields based on smooth earth theory taking into account the expected atmospheric refractivity gradient. The individual measurements are plotted with the cross representing the median field for each 100-foot mobile run, and the excursions of the vertical line representing the minimum and maximum ranges of field strength as recorded at each individual measuring location. Similar graphs were prepared for each radial path which was measured, and were included in the reports of the field strength measurement surveys.

3) *Summary of Results:* Table III has been prepared as a brief summary of the results of the field strength measurements. Each line in Table III summarizes the results of the measurements over one complete measuring route, giving the frequency of the transmission, the average height of the transmitting antenna above the best fit curve to the measuring points along the radial route,[11] estimates of the roughness of the terrain (R/λ), and the per cent of forest cover (P_f)[12] for each radial. The last column gives the average difference between the measurements along each radial and the fields predicted by the classical smooth earth curves corrected

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[11] R. M. Bowie, "The television system from the allocation engineering point of view," this issue, p. 1112.

[12] H. T. Head, "The influence of trees on television field strengths at ultrahigh frequencies," this issue, p. 1016.

FIELD STRENGTH MEASUREMENTS
WBRZ—Baton Rouge, Louisiana
59.75 mc 890 feet
(All fields in dbu for 1 kw radiated)
Direction 317°True

Distance, Miles	Ground Elevations Above M.S.L.	Standard Time	30-foot antenna 100-foot Mobile Run			10-foot antenna Cont. Mobile			Standard Time	Note
			Minimum	Median	Maximum	Minimum	Median	Maximum		
42	45.0		42.5	43.5	43.5	18.0	25.0	30.0		18
44	40.0		41.0	42.0	42.5	14.5	28.0	36.0		19
46	50.0		40.0	40.5	40.5	9.0	23.0	31.0		20
48	44.0		38.0	39.0	39.0	21.0	29.0	33.0		21
50	40.1		37.5	38.5	39.0	5.0	27.5	34.0		22
52	45.0		35.0	35.5	37.0	6.0	20.0	25.0		23
54	45.0		34.0	35.0	35.5	14.5	21.0	25.0		24
56	55.0		37.0	38.0	38.5	7.0	21.0	23.0		25
58	50.0		34.0	35.5	36.0	5.0	17.5	19.0		26
60	60.0		28.0	29.5	31.0	6.0	16.5	22.5		27
62	45.0		27.0	28.5	29.0	9.0	16.0	23.5		28
64	50.0		21.5	22.0	26.0	6.0	14.5	24.0		30
66	50.0		27.0	29.0	32.0	5.0	11.0	16.0		31
68	75.0		25.0	27.0	28.0	5.0	14.0	21.0		32
70	75.0		26.0	28.5	29.5	7.0	12.5	21.0		33
72	50.0		23.5	25.0	28.0	5.5	12.5	17.0		34
74	50.0		21.0	22.0	24.0					35

Fig. 6—Sample of tabulated data from field strength survey.

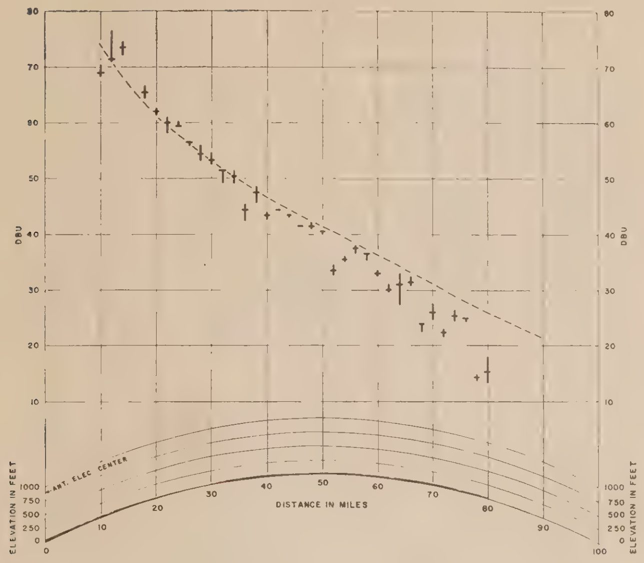

Fig. 7—Measured VHF field strengths vs distance in smooth terrain. The dashed curve is the refractivity corrected smooth earth prediction.

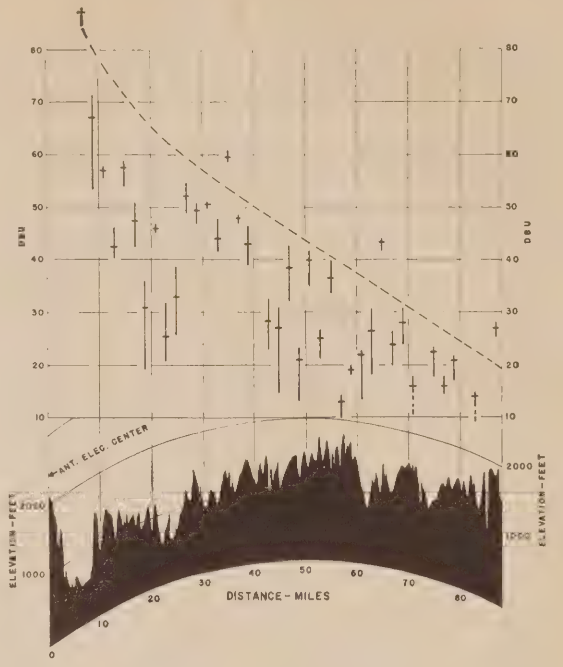

Fig. 9—Measured VHF field strengths vs distance in very rugged terrain. The dashed curve is the refractivity corrected smooth earth prediction.

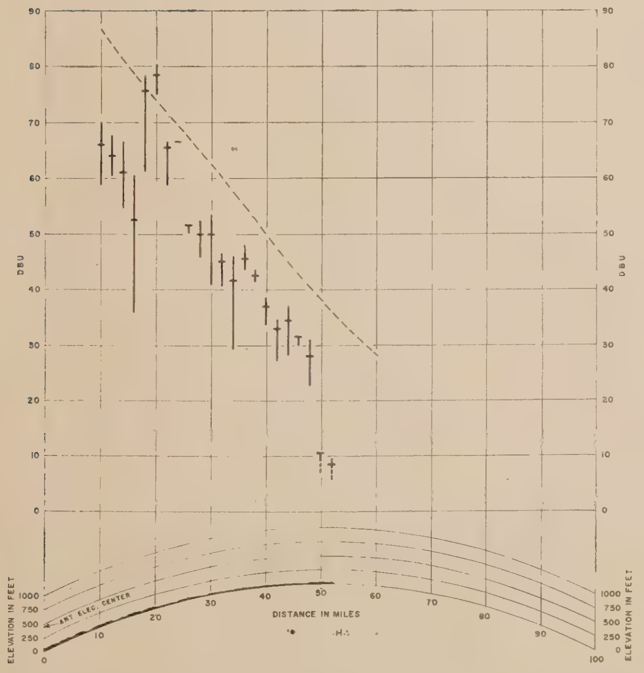

Fig. 8—Measured UHF strengths vs distance in smooth terrain. The dashed curve is the refractivity corrected smooth earth prediction.

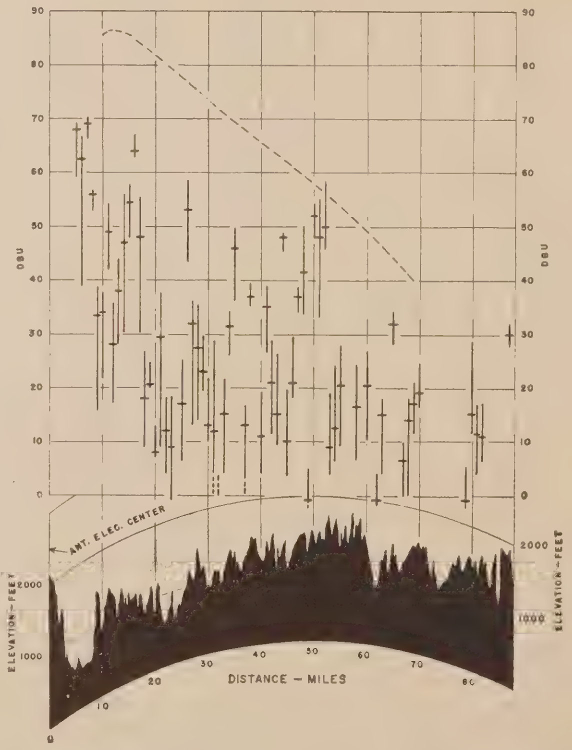

Fig. 10—Measured UHF field strengths vs distance in very rugged terrain. The dashed curve is the refractivity corrected smooth earth prediction.

TABLE III

Summary of Results of Field Strength Measurement

Frequency in mc	H_t in feet	R/λ	P_f	ΔSE in db
59.75	890	0.37	98	+0.5
59.75	900	.15	94	5.4
59.75	900	.41	35	−0.9
59.75	900	.23	39	−0.6
59.75	910	.39	82	2.2
59.75	910	.21	94	0.1
59.75	900	.40	70	0.6
59.75	880	1.6	62	2.6
59.75	230	2.2	25	6.7
59.75	670	7.8	32	−2.1
59.75	120	10.8	57	12.8
59.75	420	0.33	—	2.3
61.25	810	2.9	10	1.5
61.25	900	2.0	16	−1.7
61.25	910	2.7	10	−4.3
61.25	900	2.4	10	1.0
61.25	810	5.0	10	−2.7
61.25	620	5.2	21	−1.1
61.25	1110	6.1	32	−3.6
61.25	810	6.4	32	−1.6
90.9	430	7.8	7	−3.0
90.9	620	0.45	32	−4.2
90.9	480	2.0	70	−4.0
90.9	440	2.2	49	−1.8
90.9	580	1.0	10	−9.9
90.9	390	7.3	25	−10.5
90.9	360	12.6	28	−4.4
90.9	570	7.2	25	−8.6
93.1	1245	9.6	100	−8.9
93.1	845	24.5	81	−12.4
93.1	975	12.3	94	−13.5
93.1	1010	14.2	85	−2.8
93.1	1080	3.2	67	−5.7
93.1	860	15.7	94	−16.0
93.1	40	35.8	90	+15.0
93.1	250	31.5	76	−16.1
98.5	1920	17.0	50	−14.9
98.5	40	13.0	90	0.2
98.5	300	29.3	70	6.0
98.5	780	16.0	75	−15.2
98.5	600	17.2	78	−17.7
98.5	1270	10.2	30	−19.0
98.5	1210	33.0	100	−22.1
98.5	1620	22.6	50	−19.0
193.24	540	13.3	80	−4.0
193.24	560	9.7	62	−8.8
193.24	690	14.1	76	−2.1
193.24	740	14.3	74	−8.9
193.24	600	18.2	72	−7.7
193.24	610	9.3	78	−8.7
193.24	650	9.2	100	−3.6
193.24	430	11.0	80	2.8
209.75	4500	neg	0	−1.2
209.75	4500	neg	0	−1.6
209.75	4500	neg	0	+0.3
493.75	700	19	25	−21.6
493.75	970	135	32	−30.0
493.75	420	90	57	−32.2
559.75	490	6.0	98	−29.3
559.75	500	1.4	94	−29.0
559.75	500	6.1	35	−19.7
559.75	500	2.3	39	−12.9
559.75	510	3.4	82	−22.2
559.75	510	1.7	94	−28.1
559.75	500	1.8	70	−16.5
559.75	480	29.0	62	−22.4
559.75	1975	96.5	50	−37.7
559.75	100	74	90	−18.3
559.75	360	166	70	−30.8
559.75	840	91	75	−43.6
559.75	650	98	78	−37.0
559.75	1330	58	30	−34.4
559.75	1260	187	100	−40.5
559.75	1680	128	50	−49.9
585.26	690	27.2	10	−12.8
585.26	780	18.7	16	−24.7
585.26	790	25.5	10	−19.9
585.26	780	22.3	10	−21.3
585.26	690	47.7	10	−33.0
585.26	500	48.7	21	−20.2
585.26	990	57	32	−35.2
585.26	690	60	32	−36.0
601.74	470	51.5	7	−30.9
601.74	660	3.0	32	−14.9
601.74	520	13.2	70	−25.0
601.74	480	15.0	49	−21.3
601.74	620	6.4	10	−13.5
601.74	430	47.5	25	−33.2
601.74	400	82	28	−38.5
601.74	610	47.8	25	−24.9
631.75	1275	65	100	−29.4
631.75	875	166	81	−32.5
631.75	1005	83.5	94	−30.3
631.75	1040	96.5	85	−28.6
631.75	1110	21.7	67	−18.6
631.75	890	107	94	−38.5
669.25	4400	neg	0	+1.6
669.25	4400	neg	0	−1.4
669.25	4400	neg	0	−1.0
789.26	560	55.0	80	−22.0
789.26	580	39.7	62	−28.9
789.26	710	57.8	76	−21.6
789.26	760	58.5	74	−31.7
789.26	620	75	72	−28.4
789.26	630	38.2	78	−28.1
789.26	670	38.0	100	−37.1
789.26	450	45.0	80	−29.1

for refractivity gradient. In evaluating these results, it should be borne in mind that classical theory predicts considerably higher fields within the radio horizon on the higher frequencies.

Table III provides an indication of the magnitude of the measuring program undertaken. Each line in Table III represents a complete radial series of field strength measurements extending out to the maximum distance to which the signals could be reliably measured. A typical series of radial measurements included 40 or more individual 100-foot mobile runs. The two mobile measuring units employed in taking most of the data traveled a distance of more than 100,000 miles in making these surveys.

Acknowledgment

TASO did not have facilities at its disposal for undertaking actual field work, and all of the measurement data submitted were provided on a voluntary basis by participating organizations. The great bulk of the data supplied, including all of the surveys listed in Table II, was provided through the financial support of the Association of Maximum Service Telecasters, Inc., employing the services of A. D. Ring & Associates. The CBS Television Network, Westinghouse Broadcasting Company, George C. Davis, A. Earl Cullum, Jr., Jansky & Bailey, Inc., and James C. McNary also contributed data.

Forecasting Television Service Fields*

ALFRED H. LaGRONE†, SENIOR MEMBER, IRE

Summary—**The propagation of VHF and UHF television signals over a spherical, irregular surface such as the earth is examined theoretically and experimentally and the principal factors evaluated. The principal factors are found to be frequency, meteorology, terrain and vegetation. It is shown that meteorology, terrain and vegetation vary a significant amount geographically and that local values should be used in forecasting local service fields.**

The principal factors are included in a new empirical method suggested for forecasting the service fields of television stations. The signal forecast by the new method is compared with field-measured signals with good results.

INTRODUCTION

THE operation of all television stations in the United States comes under the supervision of the Federal Communications Commission. It is the responsibility of this body to allocate channels, effective radiated power, and location of stations to serve the maximum interest of the public. In this connection, it is of prime importance to the FCC to have accurate information regarding the propagation of radio waves at all television frequencies over a spherical irregular surface such as the earth.

In the early days of television broadcasting, allocations were made on the basis of predicted coverage using conventional propagation theory. This method was used until field reports from operating stations showed it to be inadequate. A study was then made of all available field data in an effort to develop propagation curves that were more reliable. Statistically derived curves were developed from the study for the low VHF and high VHF bands. Curves for the UHF band were not derived because of the lack of sufficient field measured data at the UHF frequencies. However, the limited UHF data available indicated that the low-band VHF curves were in close enough agreement to the UHF measurements to be useful. At a later date, UHF curves were developed but were never generally accepted and were little used.

In 1956, representatives of the television broadcasters and manufacturing industries, at the request of the Federal Communications Commission, established the Television Allocations Study Organization (TASO). It was the purpose of this organization to obtain the best technical advice and information that could be obtained regarding the transmission of a picture from a transmitter to the viewer's screen. The ensuing study by TASO covered all aspects of the television problem, including a re-examination and evaluation of the factors affecting the propagation of television signals and of the propagation curves then in use. This phase of the study yielded a new method for forecasting service fields, including an empirical equation for including terrain effects. This paper is a report on this phase of the TASO propagation study.

METEOROLOGY

Radio waves propagating in the troposphere travel curved paths instead of along straight lines because of the decrease in refractive index with height. Normally, the decrease in refractive index with height is not sufficient at VHF and low UHF to accomplish total trapping; however, some strong gradients do exist at times and partial trapping occurs. These are regarded as anomalous conditions. The normal decrease in refractive index with height causes the wave to bend considerably less than that required for total trapping but it is sufficient to require consideration when computing service fields for a given transmitter. It is customary to take the bending effect into account by modifying the earth's radius "a" to "ka" in the propagation equations.[1] This modification is based on a so-called standard atmosphere which gives a value of four-thirds to the coefficient "k." The product "ka" is referred to as the modified earth radius.

The four-thirds earth radius has been used for many years in computing radio signal strengths and is still useful in the absence of more specific information. A program of regular radiosonde measurements at distributed stations over the Continental United States by the U. S. Weather Bureau can now provide specific information on the amplitude distribution of the refractive index with height at the various stations, so that it is possible to obtain more accurate information on the modified earth radius to be used at given locations. Figs. 1 and 2 show contours of "k" in the United States for the winter and summer periods obtained from the Weather Bureau data.[2]

An examination of the contours of "k" in Figs. 1 and 2 shows larger values of "k" in the Gulf Coast area and along the Atlantic seaboard than in the interior areas. Broadcasters have long recognized the better broadcast conditions in this region and have labeled it Zone 3 which indicates greater service area for the same facilities. Figs. 1 and 2 also show that average propagation conditions along individual radials for a given transmitter may differ by a significant amount.

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* Original manuscript received by the IRE January 25, 1960. This is a report of TASO Committee 5.4 on Forecasting Television Service Fields.

† Bureau of Engrg. Res., The University of Texas, Austin, Tex.

[1] J. C. Schelleng, C. R. Burrows, and E. B. Ferrell, "Ultra short wave propagation," PROC. IRE, vol. 21, p. 427; March 1933.

[2] These are preliminary curves drawn from data supplied by Mr. Bradford Bean of the National Bureau of Standards, Boulder, Colo. Mr. Bean will publish his report at a later date.

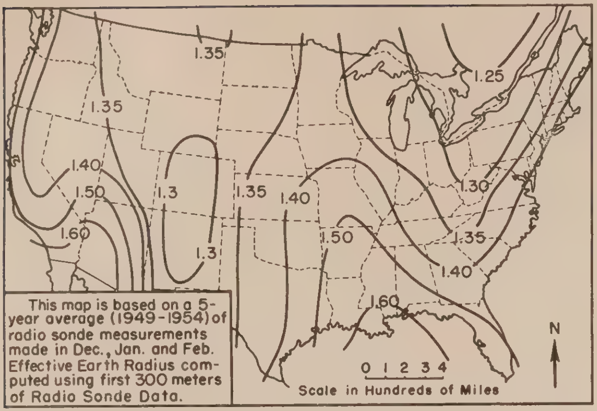
1.35
1.25
1.35
1.40
1.50
1.3
1.35
1.40
1.30
1.60
1.3
1.50
1.35
1.40
1.60
This map is based on a 5-year average (1949-1954) of radio sonde measurements made in Dec., Jan. and Feb. Effective Earth Radius computed using first 300 meters of Radio Sonde Data.
N
0 1 2 3 4
Scale in Hundreds of Miles

Fig. 1—Effective earth radius contours for winter.

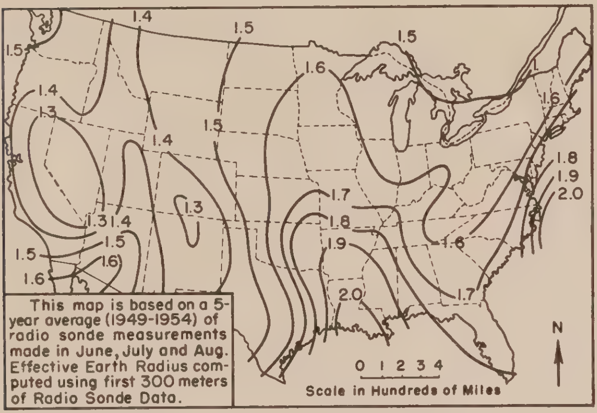
1.4
1.5
1.5
1.5
1.6
1.4
1.3
1.6
1.5
1.4
1.8
1.9
2.0
1.3
1.7
1.31.4
1.8
1.5
1.9
1.6
1.5
1.6
1.6
2.0
1.7
This map is based on a 5-year average (1949-1954) of radio sonde measurements made in June, July and Aug. Effective Earth Radius computed using first 300 meters of Radio Sonde Data.
N
0 1 2 3 4
Scale in Hundreds of Miles

Fig. 2—Effective earth radius contours for summer.

The effect of changes in diffraction on signal strength as a function of distance from the transmitter is shown in Fig. 3. The most important changes are observed to take place in the distant field. The magnitude of signal-strength change indicates that area meteorological conditions must be considered in determining the service and interference areas of VHF and UHF transmitters. Recognition should also be made of the large seasonal and diurnal variations found in some locations.

Effective Antenna Height

The effective height of an antenna is a propagation parameter used in determining the signal level in both the optical and diffraction regions of a given transmitter installation. Since no ordinary terrain is perfectly smooth, the average elevation of the two-to-ten mile section along a given radial is generally used as the reference in determining the effective antenna height. There are, of course, an infinite number of cases in mountainous regions where this approximation is inadequate. Such complex terrain must be treated as special cases and conventional methods used in point-to-point analysis.

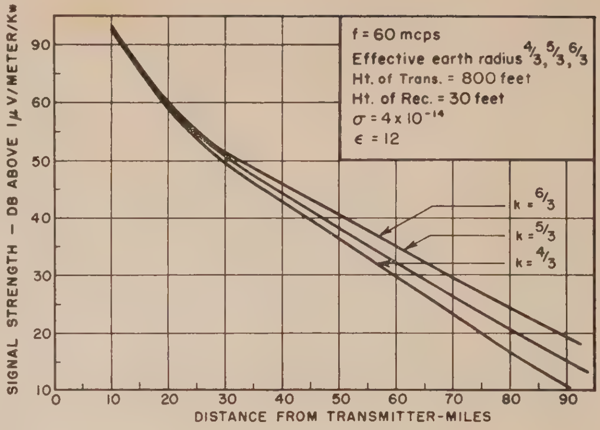

Fig. 3—Signal strength vs distance for different effective earth radii.

One example of complex terrain that occurs frequently enough to warrant special mention is that of the path that undergoes one or two major changes in elevation but is otherwise relatively smooth. Such a path might run across a valley for the first twenty miles, then rise suddenly to a plateau several hundred feet above the valley floor. The two-to-ten mile average would provide an excellent reference for the first twenty miles but would hardly be adequate for the remainder of the path. In such cases, it seems appropriate to use two effective antenna heights: one measured from the two-to-ten mile average and one measured from the average elevation of the plateau. A theoretical smooth-earth curve for the path would then be computed in two parts and joined together with a smooth transition in the vicinity of the major elevation change at twenty miles.

The diffracted field beyond the radio horizon for very rough paths is so complex that no practical methods for computing them are known. Theoretically, the diffracted field depends on the phase and amplitude distribution of all the Huygen sources in a plane passing through the diffracting edge. Practically, the field in the shadow region is determined by the phase and amplitude distribution of the Huygen sources in the first few Fresnel zones near the diffracting edge. Thus, it seems reasonable to examine the path profile for the most likely source of a reflected wave that will disturb the Huygen sources in the first few Fresnel zones. This, in most cases, is the terrain near the diffracting edge. On the basis of this argument, it is recommended that the elevation of the five-mile sector, beginning at the radio horizon and extending back toward the transmitter, be averaged and used as the reference for determining the effective transmitter height for propagation beyond the horizon.

Theoretical signal-strength curves show that the signal level becomes less sensitive to changes in transmitter height as the height increases. This means that a fairly rough path can be averaged to obtain the effective antenna height for antennas over 500 feet high with an error of not more than a few db. The two-to-ten mile rule should then be found to apply to terrain that does not vary over ±10 per cent of the effective antenna height. For terrain rougher than this, it is suggested that the path elevations from two miles out to the radio horizon be averaged and used as the reference, or that the path be treated as a special problem and conventional methods used in a point-to-point analysis.

FREQUENCY CONSIDERATIONS

The signal strength as a function of frequency is shown in Fig. 4. The relationship demonstrated in the example is maintained in most cases of interest in the VHF and UHF television broadcast bands. The important observation to be made from studying the curves is that the near field increases with frequency while the distant field decreases with frequency.

It is not likely that one could go out and measure the exact fields predicted by theory developed for a smooth spherical earth at television frequencies. Vegetation and terrain irregularities would have to be considered. Vegetation affects the received television signal in two principal ways: The effective terminal heights are reduced because the wave is reflected off the vegetation instead of the ground, and the signal is attenuated on passing through vegetation. Both effects vary with frequency and density of vegetation.

The reflection coefficient for an area of vegetation of uniform height approaches −1 at low VHF for angles near grazing incidence.[3] At 1000 mc, the same vegetation may have a reflection coefficient of −0.3 for angles near grazing. The apparent roughness is a function of frequency and can be estimated by application of Rayleigh's criterion.[4] The height at which the wave appears to be reflected is near the top of the vegetation as grazing incidence is approached. At larger angles, the wave penetrates to a depth that depends on the angle, the thickness and uniformity of height of the vegetation, and the frequency of the signal. The depth of penetration can be only approximated, as no measurements at television frequencies are known to the author that provide any useful information on the subject.

Television signals are absorbed by trees in varying amounts depending on the frequency and polarization of the signal and the density and state of the trees.[3] For moderately thick trees in full leaf with the antenna below tree-top level, the average attenuation at 30 mc is 2 to 3 db for vertical polarization and 0 db for horizontal polarization. At 100 mc, the average attenuation is 5 to 10 db for vertical polarization and 2 to 3 db for horizontal polarization. As the frequency increases, the average attenuation increases. At 1000 mc, trees that block vision are almost opaque to the radio signal. Signals reaching the receiver must then diffract over or around the trees. Above 300 to 500 mc, there is little difference in the attenuation for vertical and horizontal polarization.

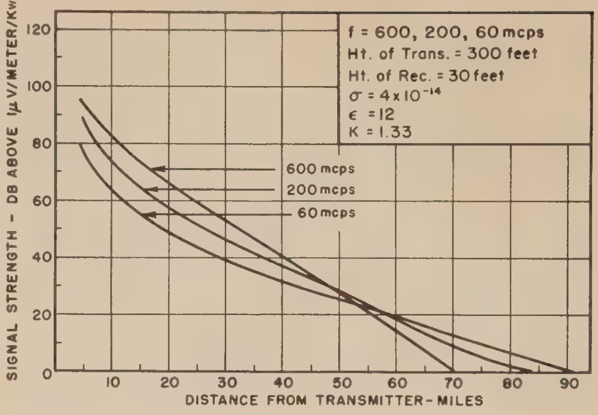

Fig. 4—Theoretical curve as functions of frequency.

Measurements of attenuation through woods in full leaf have been reported for 500 mc by B. Trevor,[5] for 100, 540 and 1200 mc by Saxton and Lane,[6] and for 3260 mc by McPetrie and Ford.[7] Their findings can be represented approximately by the following:

$$\text{db/meter} = 1.29 \times 10^{-3}(f_{mc})^{0.77}$$

where

$$\text{db/meter} = \text{attenuation}$$

$$f_{mc} = \text{frequency in mcps.}$$

No such information is available at the above frequencies for deciduous trees without leaves, although some measurements made by Trevor[5] at 500 mc indicate the attenuation to be significantly less. Trevor found that the attenuation at 500 mc dropped from 0.12 db/meter for trees in full leaf, for both vertical and horizontal polarization, to 0.1 and 0.08 db/meter, respectively, for the same trees leafless.

Fig. 5 shows the effect of trees between the receiver and the transmitter with the receiver in the clear at varying distances. It is interesting to note the clearance distance required for a significant recovery in the signal and the extremely poor signal close by the woods. The measurements were made at 485 mc near Salisbury, Md. by A. D. Ring and Associates, Consulting Engineers, of Washington, D. C.

EARTH CONSTANTS

Normal changes in earth constants for different geographical areas do not significantly affect radio propagation at television frequencies presently in use.

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[3] D. G. Fink, "Television Engineering Handbook," McGraw-Hill Book Co., Inc., New York, N. Y.; 1957.

[4] D. E. Kerr, "Propagation of Short Radio Waves," M.I.T. Rad. Lab. Ser., McGraw-Hill Book Co., Inc., New York, N. Y., vol. 13; 1951.

[5] B. Trevor, "Ultra-high-frequency propagation through woods and underbrush," *RCA Rev.*, vol. 5, pp. 97–100; July, 1940.

[6] J. A. Saxton and J. A. Lane, "VHF and UHF reception," *Wireless World*, vol. 61, pp. 229–232; May, 1955.

[7] J. S. McPetrie and L. H. Ford, "Experiments on propagation of 9.2 cm wavelengths, especially on the effects of obstacles," *J. IEE (London)*, vol. 93, pt. 3A, p. 531; March, 1946.

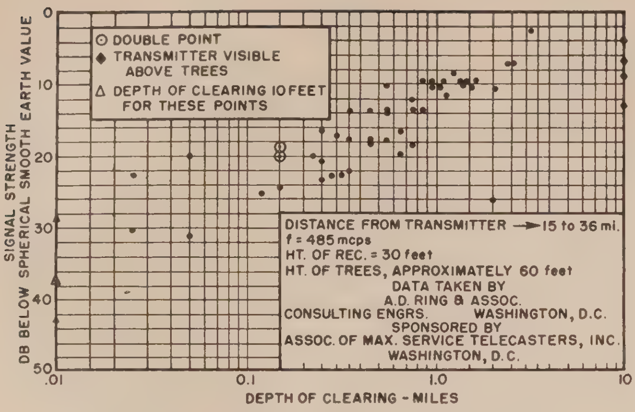

Fig. 5—Measured UHF signal strength vs depth of clearing to tall trees on radio path.

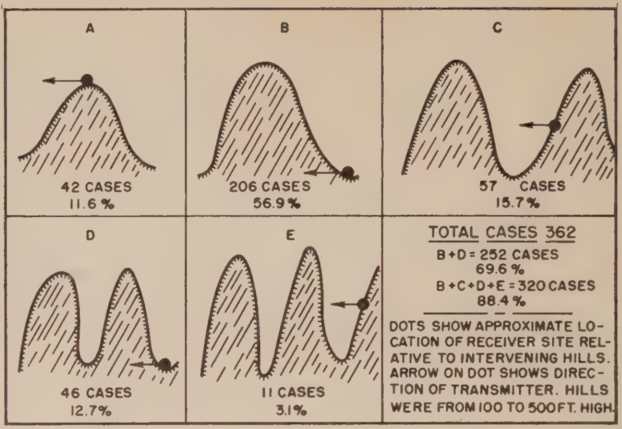
A
B
C
42 CASES 11.6%
206 CASES 56.9%
57 CASES 15.7%
D
E
46 CASES 12.7%
11 CASES 3.1%
TOTAL CASES 362
B+D = 252 CASES 69.6%
B+C+D+E = 320 CASES 88.4%
DOTS SHOW APPROXIMATE LOCATION OF RECEIVER SITE RELATIVE TO INTERVENING HILLS. ARROW ON DOT SHOWS DIRECTION OF TRANSMITTER. HILLS WERE FROM 100 TO 500 FT. HIGH.

Fig. 6—Pictorial tabulation of receiver site distribution at Wilkes-Barre, Pa.

Prédiction Techniques

Median Curves

The theoretical field over a smooth spherical earth provides a first approximation of the median signal. If local earth constants and effective earth radius are used, the computed signal should be very close to the measured signal for reasonably smooth and clear terrain.

A first approximation of the median signal can also be obtained by statistical analysis of a large quantity of field-measured data. The median signal obtained in this manner differs from the theoretical smooth-earth median because the field-measured signal is influenced by factors not considered in the smooth-earth equations. One important factor in the field-measured median is the location of the measuring site. In rough country, for example, field-measured data are taken along existing roads that invariably run in valleys, of which, some are quite deep. Fig. 6 is a pictorial distribution of the measuring sites for such an area in the TASO study. The area in question is that of Wilkes-Barre, Pa. The effect of the hills is clearly apparent in the measured signals shown in Figs. 7 and 8. When such data are included in an over-all field study it lowers the field-derived median such as the FCC's F(50, 50) and Appendix A curves. In reasonably flat or gently rolling terrain, the location of a road is not so greatly influenced by a hill and the measured median signal does not have so large a negative bias as found in the more rugged areas.

Vegetation is also an important factor is field-measured data at some television frequencies, as previously noted. At low VHF, it was found to be negligible, but at high VHF, trees and tall grasses were found to absorb a significant amount of the signal. This results in a lower median signal in the measured data. As a consequence, the signal derived from such data is lower than the median signal predicted by smooth-earth equations at the higher VHF.

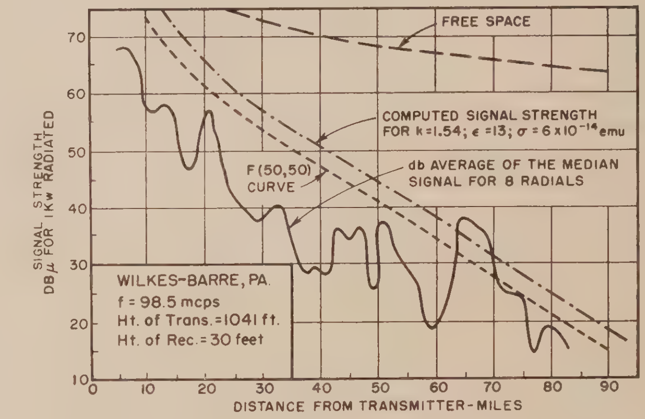

Fig. 7—Field measured average signal strength vs distance.

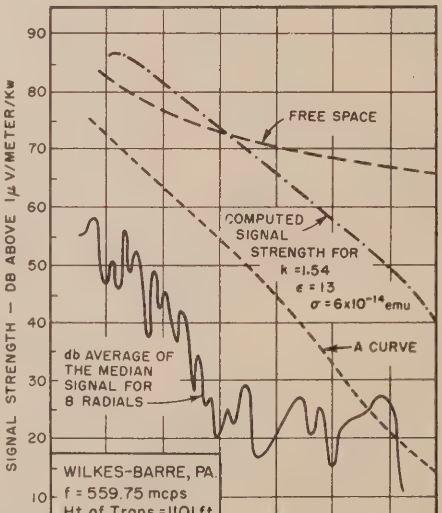

Fig. 8—Field measured average signal strength vs distance.

The absorption of radio waves by trees and grasses noted at the higher VHF was found to be considerably more at UHF. Previously, it was noted that trees thick enough to block vision were essentially opaque at 1000 mcps. A receiver on a road beside or in such a forest would then receive its signal principally by diffraction over the trees and the signal would be considerably weakened. A median curve derived from such field-measured data at UHF would then be significantly lower than that predicted by smooth-earth theory.

Another factor to be considered in a median derived from field-measured data is the effective earth radius. Data taken over a large geographical area tend to average out local values, so that the effective earth radius in the derived median is, to a first approximation, the geographical average.

The effects discussed above appear to be the major reasons why a median signal derived from field-measured data differs from the smooth-earth median. The same effects are present in varying degrees on all paths, so a median derived from field-measured data would naturally fit the measured data better in some cases than the theoretical smooth-earth median.

In determining the best method to use for predicting the median field in a given area, it is well to consider both the smooth-earth median and the statistically-derived median in arriving at a decision. A re-examination of Fig. 3, for example, shows that the smooth-earth field increases considerably with increased atmospheric refraction at distances beyond the radio horizon. Fig. 4 shows that the smooth-earth field increases with frequency in the optical region and decreases with frequency in the diffraction region. It seems logical to assume that these same parameters will affect the television signal in the same manner for a rough, vegetation-covered earth. The possibility, then, of being able to use a single statistically-derived median such as the FCC's F(50, 50) and Appendix A curves to predict the median signal for a band of frequencies is poor.

Figs. 9–11 show three cases of field-measured average signals plotted as a function of distance from the transmitter. Included are the FCC's F(50, 50) or Appendix A curves and the theoretical curve for comparison. The theoretical curve is computed for the frequency, terminal heights, effective earth radius and earth constants, as determined for the case and area involved.

An examination of the curve in Fig. 9 shows that there is very little to choose between the F(50, 50) and the computed curve in as far as a fit with the measured data is concerned. From studying this curve and others similar to it, however, it is recommended that one use the theoretical median at low VHF and lower it 1 db over its entire range. This decision incorporates in the predicted median the local meteorological conditions, the gross terrain features, the different characteristics of the near and far fields as a function of frequency, and

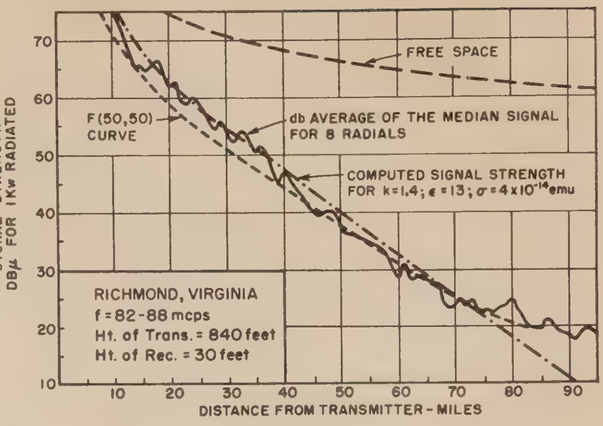

Fig. 9—Field measured average signal strength vs distance.

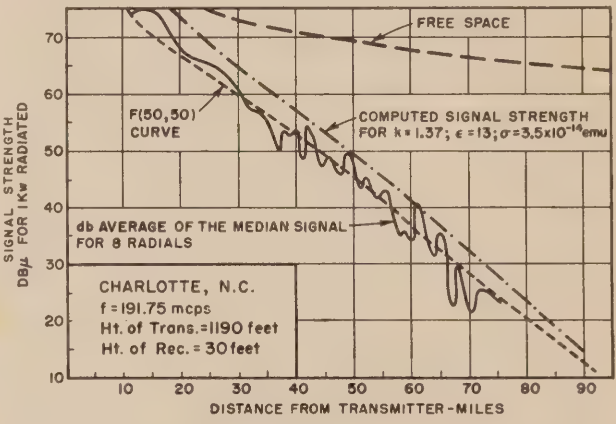

Fig. 10—Field measured average signal strength vs distance.

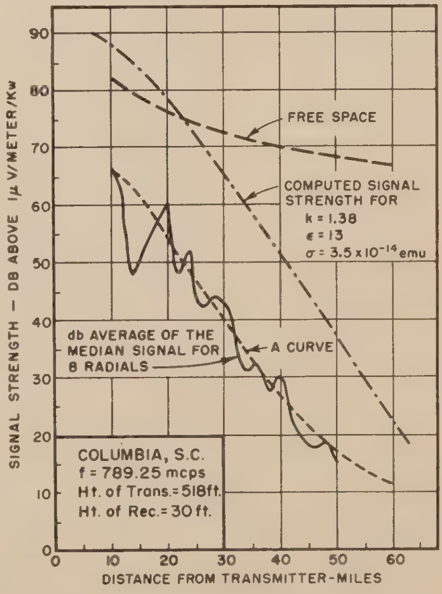

Fig. 11—Field measured average signal strength vs distance.

the small average amount of absorption noted at low VHF.

Fig. 10 is a signal strength curve in the high VHF band. A study of this and similar curves shows clearly that the F(50, 50) curve is a better fit than the theoretical curve. This is a strong argument for adopting the F(50, 50) curve as the median for this band of frequencies. A close look at the theoretical curve, however, will show just as good a fit with the measured data, if not a little better, if we lower the theoretical curve by 4 db. Based on information available to date, this appears to be the average attenuation caused by all factors at high VHF. By use of the theoretical curve instead of the F(50, 50) curve, the local meteorological conditions, the gross terrain features, and the frequency differences in propagation can also be considered. Since these are significant, the theoretical curve lowered 4 db is recommended as the predicted median.

Fig. 11 is a signal-strength curve in the UHF band. An examination of this and similar curves reveals a wide gap between the theoretical and the measured curves. The Appendix A curve, being derived from field-measured data, fits the field-measured data better than the theoretical curve. The Appendix A curve, however, is not flexible and therefore cannot be used as the predicted median for all cases. The theoretical curve considers all propagation parameters in the area and thus is the logical choice as the predicted median. Based on measurements reported to date, the average attenuation at all ranges at UHF appears to be about 22 db. This figure might be slightly larger at the higher frequencies in the UHF band. Accordingly, the theoretical curve for a smooth spherical earth lowered 22 db is recommended as the predicted median to be used at UHF.

Departure of Signal from Median

Equations are available in reference books for computing the field diffracted over objects of simple design such as spheres, cylinders and straight edges, and multiples or combinations of the above. Methods are also available for approximating the field diffracted over one or two simple hills.[3,8,9] Such methods can usually be applied with success on ridges and hills that approximate the models, but there are many cases that are too complex for these methods to be very useful.

An empirical method for obtaining the field strength is presented here that is based on the predicted median and the estimated departure of the signal from the median. The departure signal is an estimate of the effects of diffraction. Terrain and distance are the principal factors considered. Absorption, caused by vegetation, is included in establishing the median. Other local factors that might affect the signal require an on-the-spot evaluation, and such information is not usually obtainable from a topographical map.

In developing the equation for estimating the effects of diffraction, the theory of diffraction was studied and a large number of field-measured cases were examined. The study revealed that a quick estimate of the effect of a hill could be obtained by taking the square root of the height of the hill above the receiver site. The figure thus obtained was an approximation of the drop in the signal in decibels below the median. In equation form,

$$\text{db} = -\sqrt{h_1 - h_r}, \tag{1}$$

where

h_1 = elevation of hill top in feet above mean sea level [Fig. 12(A)],
h_r = elevation of receiver site in feet above mean sea level [Fig. 12(A)].

An improvement in (1) was made by including the distance of the receiver from the hillside, the height of the receiver above the intervening valley, if there was one, and including the effects of other hills between the receiver and the transmitter. Eq. (1) was then modified as follows:

$$\text{db} = c\left[-\left|h_1 - h_2\right|^{1/2}e^{-d_{1r}} - \left|h_2 - h_3\right|^{1/2}e^{-d_{2r}} + \left|h_3 - h_r\right|^{1/2}e^{-d_{3r}}\right], \tag{2}$$

where

the sign of the term is the same as the slope between the two points involved, and (2) is set up for the profile shown in Fig. 12(G),
h_2 and h_3 are elevations in feet above mean sea level [Fig. 12(G)],
d_{1r}, d_{2r} and d_{3r} are distance in miles as measured in Fig. 12(G),
$c \cong 1.6$ for VHF,
$c \cong 2.2$ for UHF.

Fig. 12 shows several other samples of terrain and illustrates the method used in measuring the various path parameters used in (2). It was not possible to illustrate every possible path configuration that could arise; however, it is felt that those shown are sufficient to illustrate the method properly. For the terrain in examples (A) and (B) of Fig. 12, for instance, the equation contains a single term. For examples (C), (D), (E), and (F), the equation contains two terms.

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[8] A. N. Kalinin, "Approximate Methods of Calculating the Field Strength of Ultra Short Radio Waves, Taking Into Consideration the Influence of the Local Terrain," Natl. Bur. of Standards, Washington, D. C., translated from Russian by J. W. Herbstreit and K. Warren, transl. no. 6005; September, 1958.

[9] J. Epstein and D. W. Peterson, "A method of predicting the coverage of a television station," *RCA Rev.*, vol. 17, pp. 571–582; December, 1956.

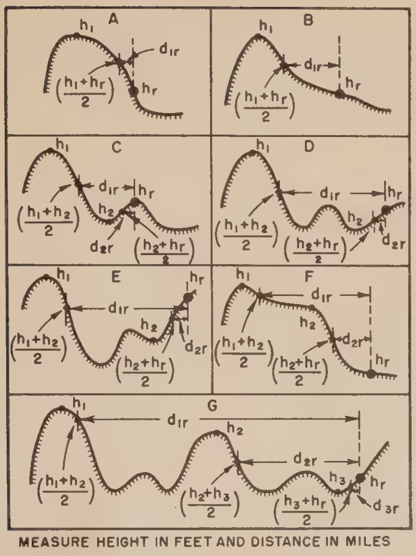
A
B
C
D
E
F
G
h_1
h_2
h_3
h_r
d_{1r}
d_{2r}
d_{3r}
$\left(\frac{h_1+h_r}{2}\right)$
$\left(\frac{h_1+h_2}{2}\right)$
$\left(\frac{h_2+h_r}{2}\right)$
$\left(\frac{h_2+h_3}{2}\right)$
$\left(\frac{h_3+h_r}{2}\right)$
MEASURE HEIGHT IN FEET AND DISTANCE IN MILES

Fig. 12—Sample cases of terrain.

Forecast and Measured Signal-Strength Curves

Three sample curves are shown in Figs. 13 and 14, comparing the forecast with the measured signal strength at VHF and at UHF. The correlation is found to be very good in areas where the terrain factors dominate the field strength variations. In relatively smooth areas, local factors not included in the departure equation produce variations that are not included in the forecast signal. Some of these variations could probably be accounted for in field data obtained specifically for such a study as made here.

Conclusion

The following recommendations or presentations are made on the basis of theory or on the basis of field-measured data analyzed to date:

1) Meteorological effects on the propagation of television signals are significant. The average conditions over the Continental United States vary enough to require local consideration in propagation studies.

2) The two-to-ten mile average of the elevation along a given radial is satisfactory in reasonably smooth terrain for determining the effective antenna height for propagation along the radial. In rough terrain, the average of a longer path than the two-to-ten mile section is recommended. For beyond-the-horizon propagation in rough terrain, the average of the five-mile sector from the radio horizon back toward the transmitter is recommended as the reference elevation for determining the effective antenna height. Some paths are so complex that they constitute special problems and must be treated by special methods.

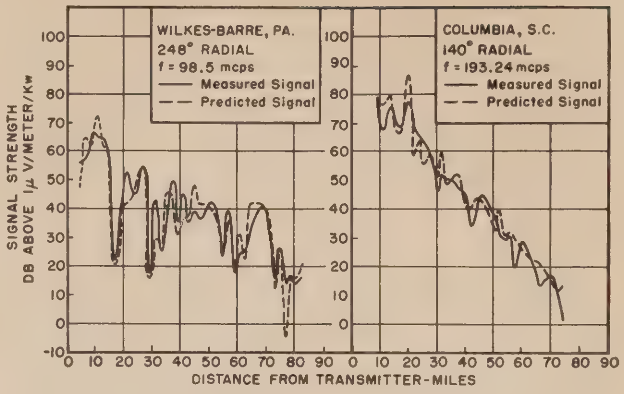

Fig. 13—Predicted and measured signals at low and high VHF television bands.

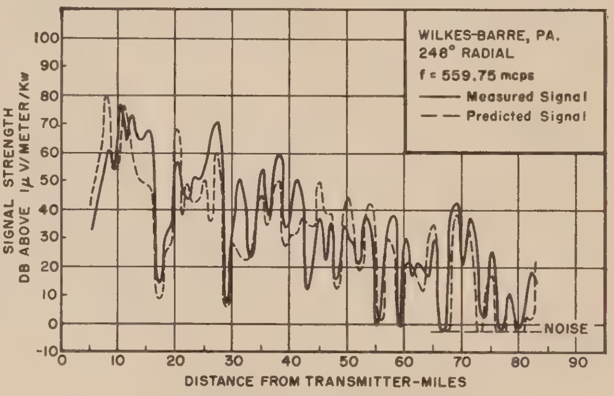

Fig. 14—Predicted and measured signal at the UHF television band.

3) The frequency characteristics of propagation, neglecting absorption, are sufficiently different, even for frequencies in the same band, to require individual consideration for forecasting signal strengths as a function of distance.

4) Normal changes in the earth constants for different geographical areas do not significantly affect radio propagation at television frequencies.

5) The theoretical signal computed at a given frequency using smooth spherical earth equations and considering gross terrain features, local meteorological conditions, and local earth constants, is recommended as the predicted median television signal under the following conditions:

a) at low VHF, the median is lowered 1 db,
b) at high VHF, the median is lowered 4 db,
c) at UHF, the median is lowered 22 db.

6) An empirical method for estimating the departure signal from the median in a given area is presented. The estimated departure combined with the predicted median gives the predicted signal.

The Influence of Trees on Television Field Strengths at Ultra-High Frequencies*

HOWARD T. HEAD†, SENIOR MEMBER, IRE

Summary—**Field studies of UHF wave propagation between television transmitting and receiving antennas indicate that typical woods are essentially opaque at these frequencies. The signal in the presence of woods near the receiving antenna appears to be principally that diffracted over the trees, with a small residual "leakage" field observable where the diffracted fields are very weak.**

The results of measurements are compared with diffraction theory, and the attenuation below free space fields due to the woods is found to be in good agreement with that predicted for a spherical obstacle having a four-thirds earth's radius. The conclusions are applied to the estimation of average losses in large areas.

INTRODUCTION

ONE of the more serious aspects of the problem of providing television service at the ultra-high frequencies has been the failure in many instances to obtain RF field strengths within the service areas as high as predicted by classical propagation theory. It has been generally appreciated that rough terrain and heavy vegetation have depressing effects on the received signal. The recognition of the effects, however, has been mainly qualitative, with no clear understanding of the absolute or relative magnitudes of the respective losses.

Recent work by LaGrone[1] at the University of Texas and others has provided a reasonable quantitative assessment of the influence of rough terrain on the received signal.[2-4] However, even after due allowance has been made for the reduction of signal caused by rough terrain, the observed median field strength is often still substantially below that predicted by classical theory. LaGrone, in his report to the Television Allocations Study Organization, recommends that smooth earth predictions at the ultra-high frequencies (470 mc to 890 mc for television service) be reduced by 22 db to provide basic curves from which further departures due to terrain irregularities are predicted.

EXPERIMENTAL PROGRAM

To determine how much UHF signal reduction might be ascribed to the effects of trees, a program of field strength measurements was undertaken in the vicinity of Salisbury, Md., during December, 1958 and January, 1959. This area was selected (see Fig. 1) because the terrain is very flat, because new topographic maps showing woodland cover were available, and because a television transmitting station (WBOC-TV) was in operation with a transmitting antenna height (620 feet above terrain) reasonably characteristic of stations in regular operation. The transmitter operates on television channel 16, which occupies the frequency band from 482 mc to 488 mc. The visual and aural carrier frequencies are 483.26 mc and 487.76 mc, respectively. The radiated power is approximately 20 kw, essentially omnidirectional in the horizontal plane.

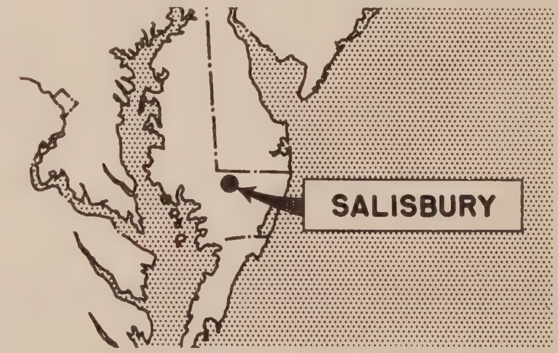

Fig. 1—Field strength measurements to determine the effects of trees were made on WBOC-TV, 482–488 mc, Salisbury, Md.

Field strength measurements on the WBOC-TV signal were made at locations selected to provide transmission under varying conditions over, through, and around woods. At each location selected for measurement, the field strengths were measured using a short, mobile run in accordance with the measuring technique specified by Panel 4 (Propagation Data) of the Television Allocations Study Organization. In a few instances where the mobile run was impractical, a "cluster" of spot measurements was substituted. The use of the mobile run or "cluster" technique introduces an averaging process which tends to smooth out small-area variations caused by standing wave patterns or other local influences.

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* Original manuscript received by the IRE, February 16, 1960 This work was sponsored by the Association of Maximum Service Telecasters, Inc.

† A. D. Ring and Associates, Washington, D.C.

[1] A. H. LaGrone, "Forecasting Television Service Fields," this issue, p. 1009.

[2] K. Bullington, "Radio propagation variations at VHF and UHF," PROC. IRE, vol. 38, pp. 27–32; January, 1950.

[3] D. G. Fink, "Television Engineering Handbook," McGraw-Hill Book Co., Inc., New York, N. Y.; 1957.

[4] J. Epstein and D. W. Peterson, "A method of predicting the coverage of a television station," *RCA Rev.*, vol. 17, pp. 571–582; December, 1956.

All of the measurements were made with a receiving antenna height of 30 feet above ground. The details of the equipment and technique utilized in making these measurements have been described in a previous article.[5]

Measurements were made over transmission paths which fall into three general categories:

1) unobstructed ray paths between transmitting and receiving antennas;
2) ray paths obstructed by groups of trees sufficiently small that the signal would be propagated principally through, rather than around, the trees (these are referred to as "thin screens" of trees);
3) ray paths obstructed by groups of trees sufficiently large that the signal would be propagated principally around, rather than through, the trees (these are referred to as "thick screens" of trees).

Measuring locations in this last category were chosen so that the obstructing mass of trees occurred at varying distances from the receiving antenna in the direction of the transmitting antenna. The distance from the receiving antenna to the woods is referred to as the "clearing depth" (see Fig. 2).

Discussion of Results

A survey of the literature reveals only scant references to the effect of trees and foliage on the received signal at the ultra-high frequencies. Trevor[6] in the United States and Saxton and Lane[7] in Great Britain have published results showing the attenuation of the signal when the transmission path is entirely through vegetation. Some classified NDRC reports from World War II include similar data. The available data are reasonably consistent and show relatively severe attenuation of signals at these frequencies when the transmission path lies entirely through trees and underbrush. The conclusions, as summarized by Saxton and Lane, are shown in Fig. 3.

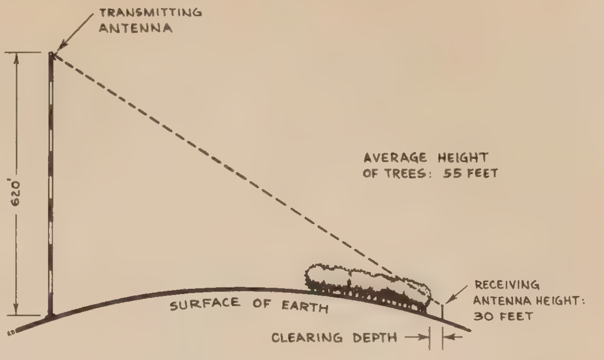
TRANSMITTING ANTENNA
620'
AVERAGE HEIGHT OF TREES: 55 FEET
SURFACE OF EARTH
RECEIVING ANTENNA HEIGHT: 30 FEET
CLEARING DEPTH

Fig. 2—The typical television transmission path is basically different from that in which both transmitting and receiving antennas are surrounded by trees.

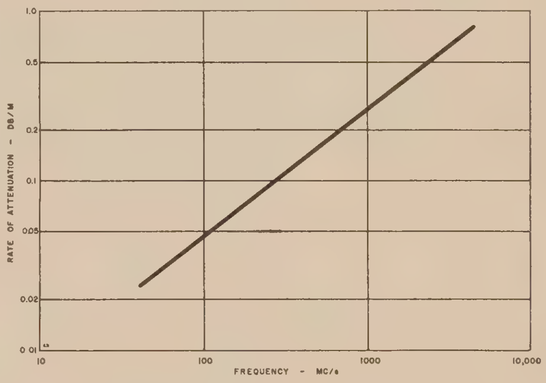

Fig. 3—Rate of attenuation in woods with trees in leaf as a function of frequency (after Saxon and Lane).

Measurements were made at thirteen locations in the Salisbury area of the attenuation of the signal in passing through thin screens of trees ranging in thickness from 8 meters to 480 meters. The results of these measurements are in reasonably good agreement with the conclusions of Saxton and Lane, but the rate of attenuation shows a decreasing trend with increasing woods thickness. This variation is probably due principally to the fact that the typical television transmission path is basically different from that for the condition where both the transmitting and receiving antennas are surrounded by trees.

In the latter situation, the entire ray path must pass through the obstructing vegetation. For typical television transmission, however, only a small part of the transmission path may pass through trees and underbrush. The transmitting antenna is usually several hundred feet high, and only within a few miles of the receiving antenna is the signal obliged to cope with trees and underbrush near the ground. This is illustrated in Fig. 2, which shows a typical ray path for transmission between television transmitting and receiving antennas. For a path such as that shown, substantial amounts of the signal may be diffracted over and around the trees. The presence of the diffracted signal is most noticeable when the vegetation is dense enough to reduce the signal transmitted through the trees to a very low value.

The first measurements made in the Salisbury area were intended to permit a determination of the signal arriving at the receiving antenna in terms of the attenuation in passing through various thicknesses of woods. Examination of the first results, however, showed little correlation with woods thickness, and a comparison with the Saxton and Lane curve (Fig. 3) revealed that the thicknesses being employed were so great that the signal arriving through the woods should be well below the noise level of the measuring equipment; nevertheless, measurable signals were being received. A further study of the measurements showed that the relative signal levels were lowest when the receiving antenna was closest to the edge of the woods between the transmitting and receiving antennas, increasing as the clearing depth (see Fig. 2) increased.

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[5] H. T. Head, "Measurement of television field strength," *Elec. Engrg.*, vol. 77, pp. 298–302; April, 1958.

[6] B. Trevor, "Ultra-high frequency propagation through woods and underbrush," *RCA Rev.*, vol. 5, pp. 97–100; July, 1940.

[7] J. A. Saxton and J. A. Lane, "VHF and UHF reception—effects of trees and other obstacles," *Wireless World*, vol. 61, pp. 229–232; May, 1955.

A preliminary analysis showed the signal to increase approximately in proportion to the logarithm of the clearing depth for clearing depths greater than approximately 0.01 mile, but at very close distances to the woods the signal level appeared to be more or less unrelated to the clearing depth. This is illustrated by Fig. 4, which shows the difference between the smooth-earth predictions and the actual observations plotted vs the logarithm of the clearing depth. The straight line is a least-squares fit to the data points beyond 0.01 mile. The standard deviation from the line is 4.1 db.

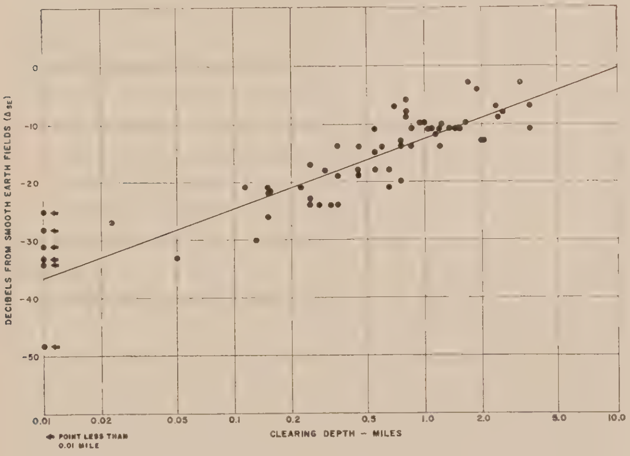

Fig. 4—Depression of signal below smooth-earth values as a function of clearing depth.

Comparison with Diffraction Theory

The basic theory of the diffraction of electromagnetic energy around the edge of a partially or completely opaque object is well established. Particular solutions, however, have been obtained only for a number of special cases, and the typical practical problem may bear little resemblance to the idealized situations for which theoretical solutions have been derived. Also, it is often difficult to foretell from the geometry of the practical case which of the particular theoretical solutions represents the model most closely resembling actual transmission conditions.

The Salisbury data were separated into two groups. In the first group were the thin screen measurements, in which it appeared that the received signals represented so complex a combination of transmitted and diffracted signals that they would have little value in a diffraction analysis. The remaining measurements, consisting of the thick screen measurements and unobstructed ray path measurements, were grouped together and tabulated. For each observation, there was determined the depression of the measured field below the smooth-earth value (Δ_{SE}), the depression of the field below the free-space value (Δ_{FS}), and the ratio of the obstruction of the trees in the first Fresnel zone to the radius of the zone at the point of maximum obstruction (H/H_0). Graphs of these values were plotted and compared with attenuation curves representing various modes of diffraction.[8,9]

A plot of Δ_{SE} vs H/H_0 does not exhibit particularly good correlation with the theoretical diffraction curves. However, a plot of Δ_{FS} vs H/H_0 shows that for Fresnel zone clearances greater than about -1.0, the points tend to fall in the general region of the theoretical curves for diffraction around a smooth sphere. Fig. 5 is a plot of this relationship showing a comparison with theoretical diffraction around a smooth spherical obstacle for a reflection coefficient $R=-1$ and a value of Bullington's parameter M of $M=300$.

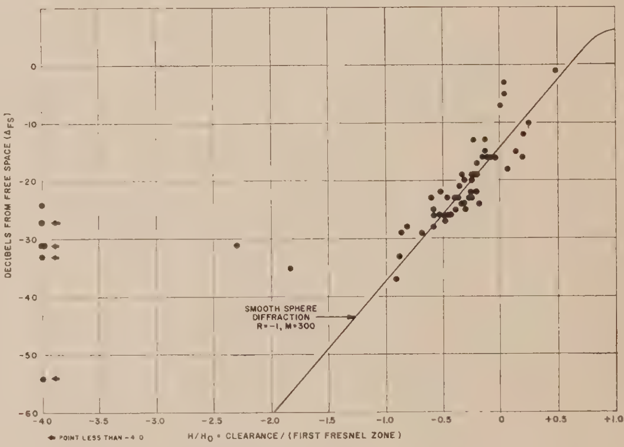

Fig. 5—Depression of signal below free-space values as a function of Fresnel zone clearance for 55-foot trees.

The parameter M is a function of transmitting and receiving antenna heights, frequency and radius of the spherical obstacle. For the heights and frequency at Salisbury, a value of $M=300$ corresponds to a smooth sphere having a radius of 24 miles. The standard deviation of the observed values from the theoretical curve is 3.4 db for Fresnel zone clearances in excess of -1.0.

The observed data were next compared with diffraction theory making the assumption that the trees ex-

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[8] K. Bullington, "Radio propagation fundamentals," *Bell Sys. Tech. J.*, vol. 36, pp. 593–626; May, 1957.

[9] A. I. Kalinin, "Approximate methods of computing the field strength of ultra short waves with consideration of terrain relief," *Radiotekhnika* (*Moscow*), vol. 12, pp. 13–26; 1957.

hibit some sort of "edge effect," due to the thinness of the upper branches, the small diameter of the top of the trunks, or other causes. Most of the tree heights for the transmission paths at Salisbury had been determined by actual measurements with a Matthews Teleheight, and the average tree heights were approximately 55 feet. The actual tops of the trees were thus some 25 feet above the receiving antenna height of 30 feet above ground.

The values of H/H_0 were redetermined assuming the existence of an "edge effect" of 10 feet; this would result in an apparent average height of the trees of 45 feet above ground, or 15 feet above the receiving antenna. The redetermined values of H/H_0 were then plotted against Δ_{FS} and the plot compared with the theoretical diffraction curves.

Fig. 6 shows a comparison of the observed values for the redetermined values of H/H_0 with the theoretical smooth-sphere diffraction prediction for $M=50$. This value of M corresponds to diffraction around a sphere having a radius equal to four-thirds of the earth's radius, the value customarily assumed in classical theory for propagation through a standard atmosphere. The standard deviation of the observed values from the theoretical curve is 2.9 db for Fresnel zone clearances greater than -0.6.

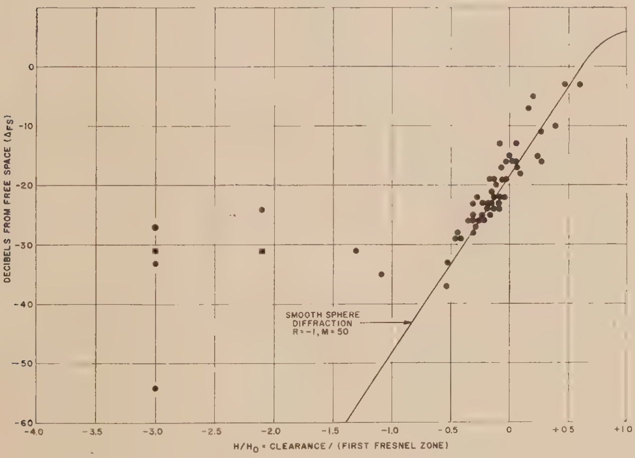

Fig. 6—Depression of signal below free-space values as a function of Fresnel zone clearance for assumed 45-foot trees.

It will be noted from Fig. 6 that the attenuation is substantially less than predicted on the basis of smooth-sphere diffraction for Fresnel zone clearance less than approximately -0.6. These values of Fresnel zone clearance represent locations where the receiving antenna was very close to the obstructing mass of trees, generally within 100 feet or less. In several instances, the receiving antenna was within 10 feet of the nearest edge of the woods.

In this region, the attenuation exhibits little correlation with any of the parameters influencing the other fields. It appears likely that the field received near the edge of the woods arrives at the receiving antenna principally through the tops of the woods and over a number of irregular paths. In making this portion of the measurements, it was frequently observed that the receiving antenna did not exhibit any clear maximum and minimum response as the antenna was rotated; in many instances it was not possible to identify the direction toward the transmitter from the orientation of the receiving antenna. The signal arriving under these conditions has been referred to as the "leakage field" (F_l) because it appears to leak through the tops of the trees, often in a rather erratic fashion.

The measurements which were considered to represent principally leakage field were analyzed for any evident trends. An examination of eight observations of leakage field at distances ranging from 12.0 miles to 22.5 miles from the transmitter indicated the average signal level below the calculated smooth-earth field to be more or less independent of distance. For these eight points, the average depression of the field below the smooth-earth field was approximately 30 db, with a standard deviation of 3.3 db.

EXTENSION OF THEORY

These observations and conclusions provide a basis for predicting loss of UHF signal strength where the loss is due primarily to the effects of trees. Consider a transmission path such as shown in Fig. 7(a). Between the transmitting antenna and the first woods at the distance D_1 there is no obstruction, and the received fields in this region are those predicted by smooth-earth theory. Beyond D_1, in the woods, the received signals are primarily those arriving through the woods, and the attenuation increases rapidly with woods thickness until the leakage field level is reached (D_2). The attenuation cannot exceed that corresponding to the leakage level, and thus any additional woods thickness does not result in further depression of the signal.

Beyond the distance D_3, where the far edge of the woods is reached, the received signals recover with distance in an approximately logarithmic fashion until the clearing depth is sufficient that the smooth-earth values are once again approached. This logarithmic recovery, which is noted in Fig. 4, can be shown to follow as a consequence of diffraction; the relationship is determined by the geometry associated with the distance between transmitter and receiver.

This model of the behavior of the field permits drawing some interesting conclusions. First, in an area completely covered with trees, or essentially so, the received signal would be largely governed by the leakage level. This level is probably a function of frequency and also of the type of vegetation. If this latter is the case, as seems likely, the leakage fields would be expected to be lower in the spring and summer than in the fall and winter. It seems probable that the relationship of the leakage field to the frequency would be similar to that

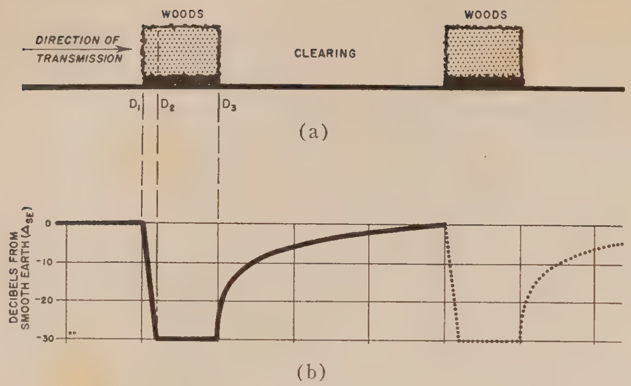

Fig. 7—(a) Model of woods and clearing for estimating average woods attenuation. (b) Depression of signal below smooth-earth values vs distance for the model of Fig. 7(a).

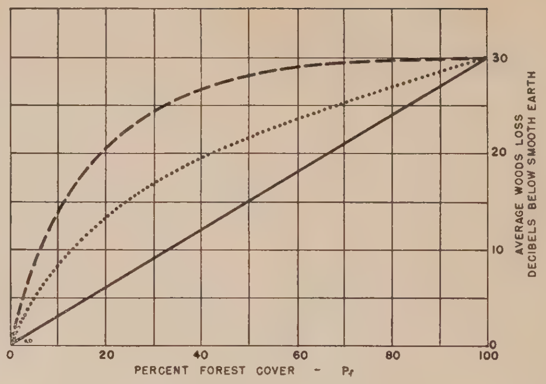

Fig. 8—Estimated average signal depression below smooth-earth value as a function of percentage forest cover P_f.

for attenuation in passing through thin screens of trees as shown in Fig. 3.

If the forest cover is less than 100 per cent, some receiving locations will be closely surrounded by trees and others partly in the clear. Theoretical models of the type shown in Fig. 7(b) were set up, and the effects of various sequences of woods and clearing were determined on the basis of the processes suggested. These studies showed that the average attenuation in an area with P_f per cent forest cover, in which the leakage field is denoted by F_l, cannot be less than $P_f F_l/100$ for any sequences of woods and clearing reasonably to be expected. For unfavorable sequences, the attenuation may be higher than this value, but an upper limit of attenuation is set by the relationship between the decay and recovery characteristics shown in Fig. 7(b). The average attenuation as a function of per cent forest cover based on this model of the behavior of the field is shown in Fig. 8. The straight line corresponds to the least attenuation of the signal for the most favorable sequence of woods and clearing, and the dashed line to the highest attenuation to be expected for the most unfavorable sequence for a given percentage of forest cover. The dotted line shown in Fig. 8 is an average attenuation curve falling between the two limits.

CONCLUSIONS

Using Fig. 8, an estimate can be made of the average attenuation of the UHF signal due to the effect of trees, provided that an estimate of the percentage of forest cover can be made. Although some modifications will probably be required for other frequencies and for vegetation under other conditions, it can be seen that the average attenuation due to the trees is on the order of the 22 db below smooth-earth values employed by LaGrone. It appears likely, based on these findings and the model of attenuation derived from them, that forest attenuation may be one of the most significant factors responsible for the average loss in signal at the higher frequencies.

Tropospheric Fields and Their Long-Term Variability as Reported by TASO*

PHILIP L. RICE†, MEMBER, IRE

Summary—**This report presents data from long-term recordings of radio field strength over a large number of propagation paths, and presents curves for predicting field strength over a smooth earth for frequencies between 40 megacycles and 1000 megacycles per second. The basic data provided for the Television Allocations Study Organization during 1957 and 1958 include recordings made in several parts of the world and over various types of terrain and were supplied by numerous sources.**

OVER the past decade, long-distance propagation in the bands above 40 megacycles per second has been carefully studied by government and private laboratories in a number of experimental programs. During 1957 and 1958, Committee 4.2 of Panel 4 of the Television Allocations Study Organization compared available data with theories of diffraction and forward scatter, and under the chairmanship of George C. Davis prepared a paper which is included as part of the final TASO report, "Engineering Aspects of Television Allocations."[1] The committee report, slightly revised and with a few additions, is presented here.

This report presents data from long-term recordings of radio field strength over a large number of propagation paths, and presents curves for predicting field strength over a smooth earth for frequencies between 40 megacycles and 1000 megacycles per second. After pointing out the extremely large variance of the actual fields received over irregular terrain relative to any set of prediction curves using distance as a parameter, and the bias of such curves arising from site selection problems, reference is made to a method which makes possible the prediction of either the service or the interference fields over specific paths for which terrain profile information is available.[2]

The basic data provided to Committee 4.2 consist of a vast number of recordings of field intensities which were made in various parts of the world and over various types of terrain. This information was supplied by numerous sources, including the Federal Communications Commission and the National Bureau of Standards. Fig. 1(a) shows median field strength, $E(50) + 10 \log_{10} d$, plotted vs the four-thirds earth distance between radio horizons, $d_s = d - \sqrt{2h_{te}} - \sqrt{2h_{re}}$ miles, for more than 600 paths in various parts of the world; d is the total propagation path distance in statute miles and $\sqrt{2h_{te}}$, $\sqrt{2h_{re}}$ are the smooth earth horizon distances where h_{te} and h_{re} are effective transmitting and receiving antenna heights in feet. A point is plotted on Fig. 1(a) for each year during which data were recorded over each path; there are, in all, 645 data points for 546 nonoptical paths and fewer data points for line-of-sight paths. One hundred and eighty-five medians correspond strictly to the period 6 P.M. to midnight, and the remainder of the data are period-of-record medians, with a few cases of duplication. The number of paths represented in each of several frequency ranges is indicated on Fig. 1(b) through 1(f).

The scatter of these data over a range of 70 decibels is due mainly to the wide variety of terrain profiles involved, and not primarily to differences in region, climate, period of record, frequency, or antenna height. Although some variance with frequency is expected, most of the paths on Fig. 1(a) correspond to frequencies near 100 megacycles per second, and thus most of the variance of these data must be attributed to terrain effects, including some variance associated with the rather arbitrary method of allowing for the effect of antenna height. Plotting these data vs distance, without any allowance at all for antenna height, the scatter would be greater.

Superimposed on the data of Fig. 1(b) through 1(f) are solid curves which represent the theoretical value of smooth earth tropospheric fields, as determined by the methods used earlier[2] for antenna heights, bracketing those represented by the data in each frequency range.

The dashed curves in each of Fig. 1(b) through 1(f) were drawn through overland U. S. data only; without a theoretical curve to follow, the dashed curve in Fig. 1(f) could not, of course, have been drawn. A considerable fraction of the data in Fig. 1(c) were biased, as will be explained later, in the direction of higher field strengths than would be expected with randomly selected receiving locations. At all frequencies the median curves through the data appear to indicate more transmission loss than would be expected over a smooth earth.

* Original manuscript received by the IRE, January 22, 1960.

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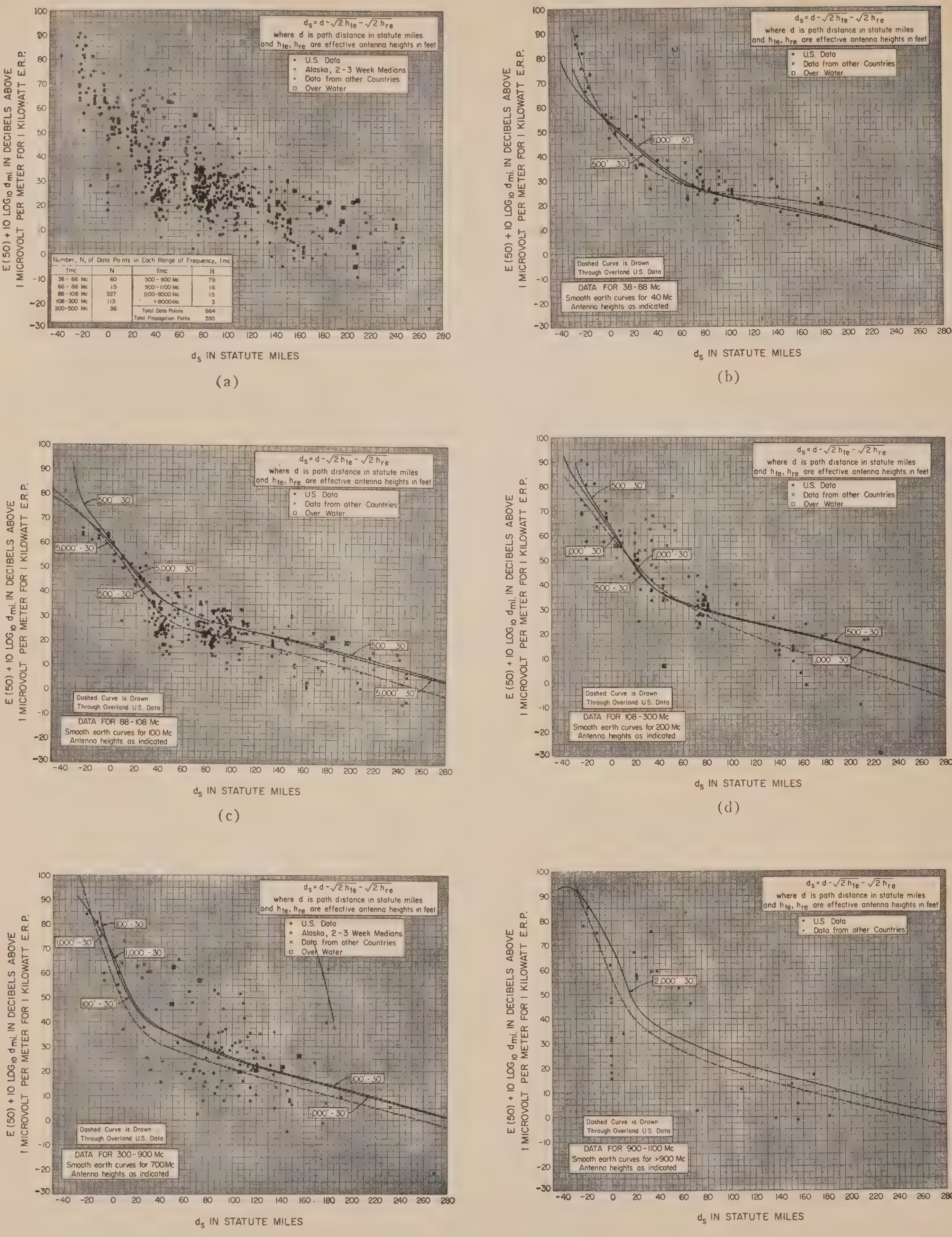
[1] Report of the Television Allocations Study Organization to the Federal Communications Commission, "Engineering Aspects of Television Allocations," March 16, 1959. (Obtainable from Dr. G. R. Town, Ames, Iowa, at a cost of $10.00.)

[2] P. L. Rice, A. G. Longley, and K. A. Norton, "Prediction of the cumulative distribution with time of ground wave and tropospheric wave transmission loss," NBS Tech. Note No. 15; July, 1959. (Available at a cost of $1.50 from the Office of Technical Services, U. S. Department of Commerce, Washington, D. C. Foreign remittances must be in U. S. exchange and must include one-fourth of the publication price to cover mailing costs.)



(a) (b)

(c) (d)

(e) (f)

Fig. 1—Median field strength $E(50)$.

Fig. 2 shows $E(50)+10 \log_{10} d$ vs d_s as calculated for a smooth earth with the assumption that the radio refractive index decreases linearly with height for the first kilometer above ground and then decreases exponentially with height.[3] These theoretical smooth earth curves happen to lie very nearly in the middle of the mass plot of data shown in Fig. 1(a). We conclude from this that the terrain irregularities over these paths are just about as likely to increase the expected field as to decrease it, at least in the frequency range in the neighborhood of 100 mc. There is some evidence at higher frequencies, however, that the median effect of the terrain is a decrease in the received field. We will see later that the medians of the fields received at randomly selected receiving sites lie well below the smooth earth curves even at 100 mc. The increase of field strength above smooth earth values in some terrain situations is associated with the phenomenon of "obstacle gain." A theory of obstacle gain is given in another paper published earlier.[4] Also, in this same paper, a method based on four different curvatures of the earth is given for calculating diffracted fields for any degree of terrain roughness, and this provides the explanation for the fact that the fields are sometimes stronger and sometimes weaker than the smooth earth values.

Fig. 3 shows all-day, all-year median field strength plotted vs distance for four frequencies and for transmitting and receiving antenna heights of 500 feet and 30 feet, respectively, using methods described earlier,[2] and assuming a smooth earth and a winter afternoon value of surface refractivity $N_s=301$ corresponding to the usual 4/3 earth. In the optical region and slightly beyond, the estimates of the difference between winter afternoons and all hours given as a function of the angular distance, θ, in the earlier work[2] are here modified slightly to allow for differences in antenna height. As the curves in Fig. 3 show, frequency does not have a large influence on the fields received over a smooth earth beyond the radio horizon.

Figs. 4–10, smooth earth curves, show all-day, all-year median field strengths at 40, 70, 100, 200, 400, 700, and 1000 megacycles per second, with one antenna height fixed at 30 feet and the other antenna height set at 100, 200, 500, 1000, 2000, or 5000 feet. The order of procedure in preparing these curves was as follows: More than a million hours were recorded over two to three hundred propagation paths. A forward scatter theory and a diffraction theory were developed. These theories were found to agree with data in all frequency ranges, for essentially any terrain and for any antenna heights. The smooth earth curves of Figs. 2–10 were prepared using these methods, as described in detail earlier.[2] On specific paths where terrain profile information and surface meteorological data are available, it is advisable to use the prediction methods directly rather than assuming a smooth earth; in this way the standard error of prediction can be reduced to a value of the order of 6 db in the diffraction region and to less than 5 db in the scatter region. The variation with frequency shown by the smooth-earth curves on Figs. 2 and 3 is smaller than that expected over a rough earth. Also, the variation with antenna height at a given frequency (illustrated in Figs. 4–10 for a smooth earth) should be taken into account in television allocations studies.

It should be noted at this point that the selection of the receiving site has a very large influence on the received median fields at large distances in this frequency range, as might be expected from the very large variance of the data illustrated on Fig. 1(a).

Another presentation of data is shown in Fig. 11, this time restricted to data which the prediction methods[2] indicate is more representative of the forward scatter (and layer reflection) propagation mechanisms than of diffraction.

Observed median values of attenuation relative to free space are plotted vs distance in Fig. 11 for a large, heterogeneous sample of data, obtained in most cases with broad beam antennas. No normalization for the effects of frequency, antenna height, loss of antenna gain, terrain or meteorological parameters is included. Almost all recordings were made in the wintertime, and correspond to conditions where tropospheric forward scatter is expected to be the dominant propagation mechanism. Two points are indicated where ionospheric rather than tropospheric scatter may have been recorded at 100 mc. No data are included for cases where diffraction is expected to be more important than forward scatter, such as short paths where the angular distance is small.

Fig. 11 also shows deviations of data from the point-to-point transmission loss prediction method;[2] these deviations are plotted vs distance, using the same data and the same scale. The NRL over-water 50-minute medians shown in Fig. 11 were excluded in calculating the rms deviation of 6.75 db from the empirical curve and the rms deviation of 5.77 db from the theoretical values.

The data include 80 paths from a special experiment conducted in Ohio with randomly selected receiving sites at 85 and 125 miles. For these paths, long-term median observed transmission loss is slightly greater than when antenna sites are carefully selected to be unobstructed. The prediction method in this report indicates an increase in transmission loss of about 12 db per degree of increase in horizon elevation angles, and

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[3] B. R. Bean and G. D. Thayer, "On models of the atmospheric radio refractive index," Proc. IRE, vol. 47, pp. 740–755; May, 1959.

[4] K. A. Norton, P. L. Rice and L. E. Vogler, "The use of angular distance in estimating transmission loss and fading range for propagation through a turbulent atmosphere over irregular terrain," Proc. IRE, vol. 43, pp. 1488–1526; October, 1955. See especially Figs. 20 and 21 and the accompanying diagram.

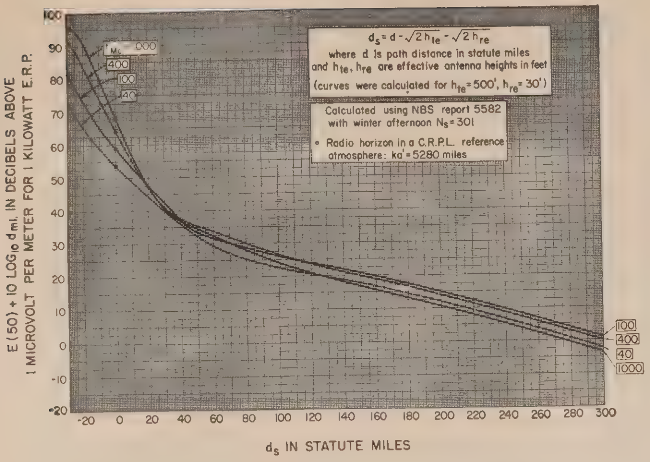


Fig. 2—All-day, all-year median field strength for paths over smooth earth.

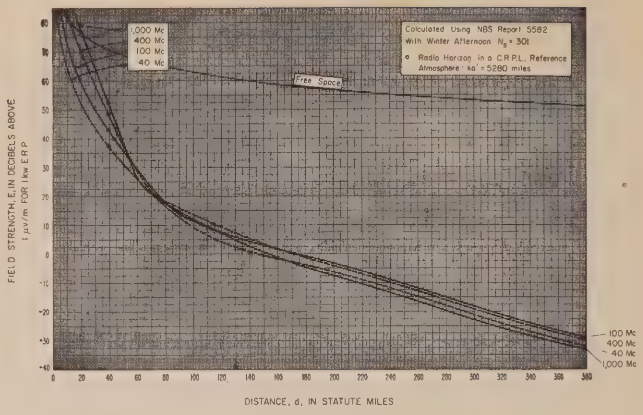


Fig. 3—All-day, all-year median field strength for paths over a smooth earth; antenna heights are 500 feet and 30 feet, frequencies are indicated.

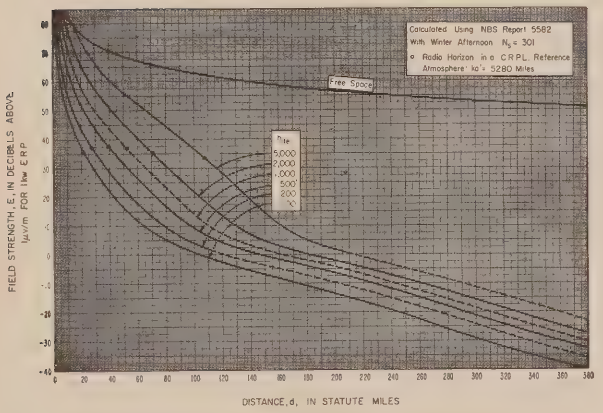


Fig. 4—All-day, all-year median field strength for paths over a smooth earth; frequency = 40 mc, one antenna height = 30 feet, other antenna height as indicated.

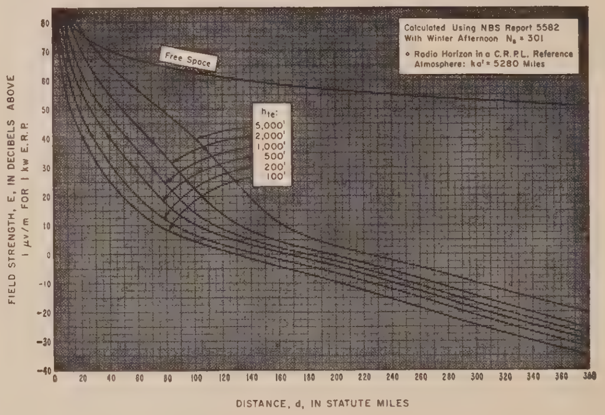


Fig. 5—All-day, all-year median field strength for paths over a smooth earth; frequency = 70 mc, one antenna height = 30 feet, other antenna height as indicated.

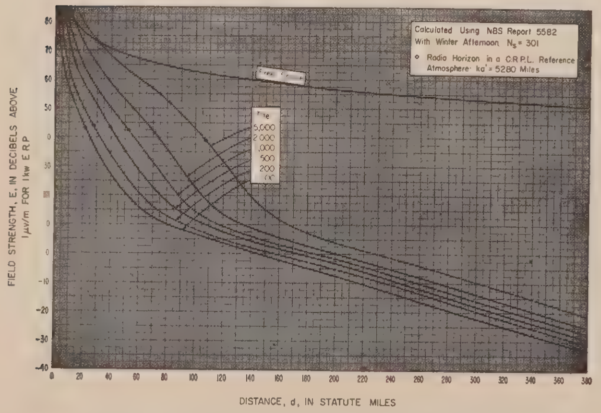


Fig. 6—All-day, all-year median field strength for paths over a smooth earth; frequency = 100 mc, one antenna height = 30 feet, other antenna height as indicated.

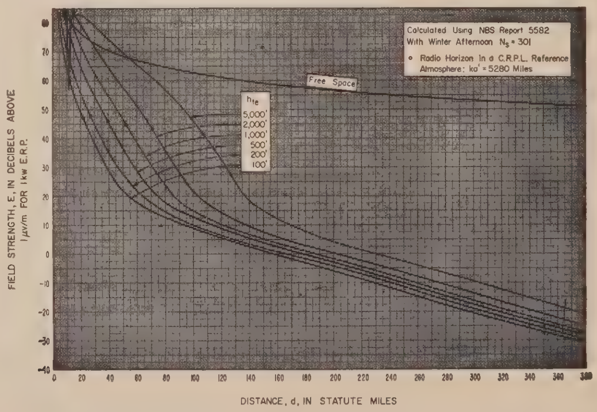


Fig. 7—All-day, all-year median field strength for paths over a smooth earth; frequency = 200 mc, one antenna height = 30 feet, other antenna height as indicated.

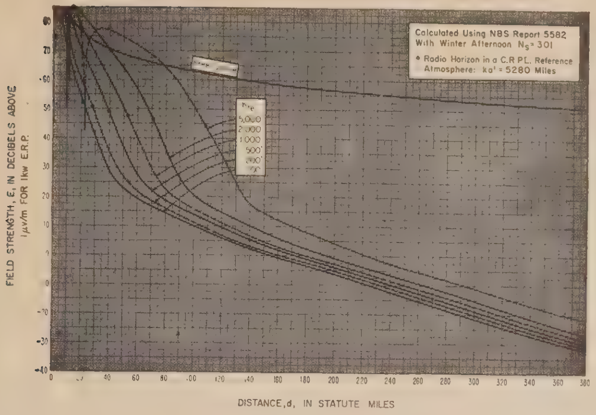


Fig. 8—All-day, all-year median field strength for paths over a smooth earth; frequency = 400 mc, one antenna height = 30 feet, other antenna height as indicated.

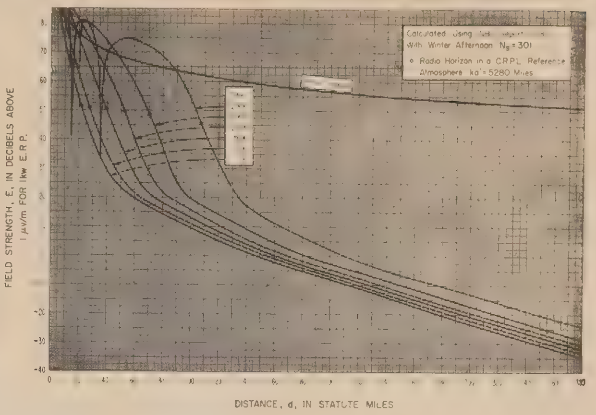


Fig. 9—All-day, all-year median field strength for paths over a smooth earth; frequency = 700 mc, one antenna height = 30 feet, other antenna height as indicated.

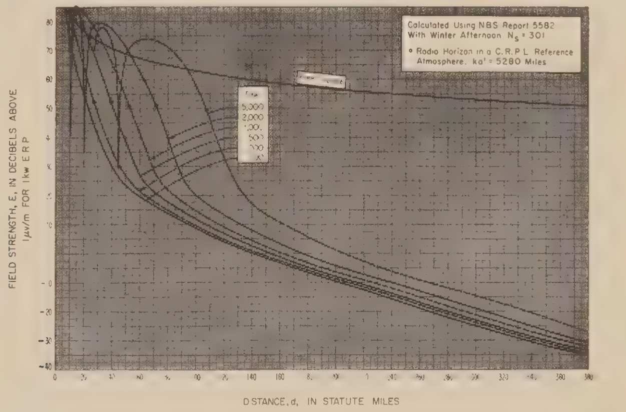
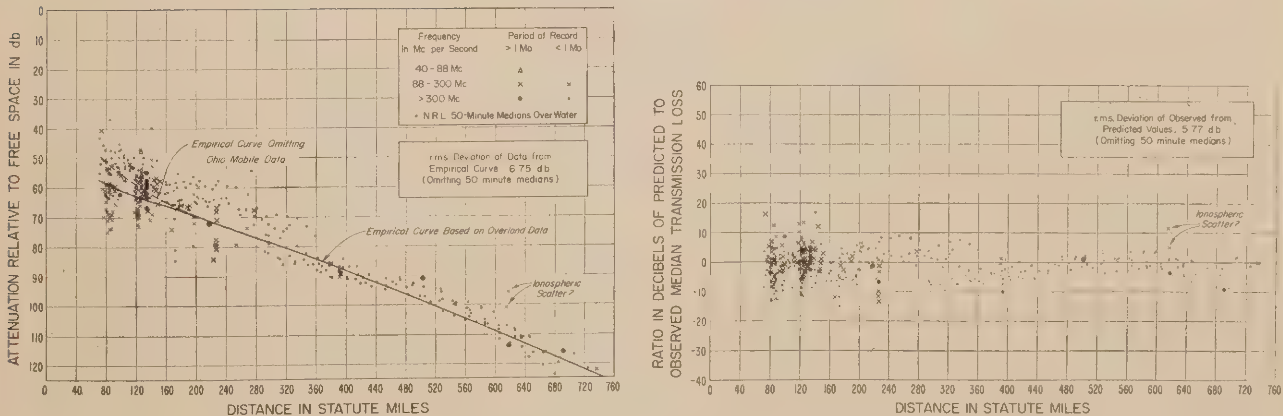


Fig. 10—All-day, all-year median field strength for paths over a smooth earth; frequency = 1000 mc, one antenna height = 30 feet, other antenna height as indicated.



(a) (b)

Fig. 11—(a) Median forward scatter radio transmission loss relative to free space corresponding to winter afternoon conditions. (b) Deviation of medians recorded in (a) from values predicted for an exponential atmosphere using NBS Technical Note 15.

these angles were often large for the randomly selected "Ohio mobile" receiving sites.

An experiment conducted in Ohio between 1951 and 1953 by James S. Hill and Carl E. Smith, then of the United Broadcasting Company, monitored two FM transmitters for a year at 20 randomly selected sites at 85 miles, and 20 more sites at 125 miles and showed field strengths well below the average of the 100 mc data on Fig. 11. The 40 receiving sites were chosen without regard to the usual criteria used in selecting receiving sites for long term recordings (namely, in open, relatively flat terrain with no nearby trees or overhead wires), but were chosen instead as nearly as possible on a preset lattice with separations between locations large enough to make the correlation of the received fields for adjacent receiving points negligible. This insured randomness with respect to terrain effects and efficiency in the recording program. Some compromise with the grid was naturally necessary in order to find sites at which power would be available and for which the property owner's access rights were available. The recordings were made over a two-year period from July 3, 1951 to June 30, 1953, and represent all-day, all-year conditions. The recordings were made in mobile laboratories which were moved frequently from one site to the next in order to obtain a good sampling of the seasonal and diurnal effects at each of the 40 receiving locations. A sufficient number of hours of recording were available so that fields $E(1)$, representative of the highest 1 per cent of the hours, could be determined for each path. The recording pen went off scale some of the time, and, as indicated in Table I, the $E(1)$ values were greater in a few instances than the recorded values. Thus, the true mean 1 per cent values are also greater than tabulated values of $\overline{E(1)+10 \log_{10} d}$. In order to obtain a measure of this possible bias, medians of $E(1)+10 \log_{10} d$ are also listed; it appears that the bias is negligible.

Receiving antennas were always 30 feet above the local terrain, while the transmitting antenna effective heights were obtained by finding the height of the transmitting antenna relative to a parabolic curve fit to the central 0.8 of the terrain between the transmitting antenna and its standard atmosphere (4/3 earth radius) horizon.

Table I lists 12 estimates of the variance s_T^2 of the 20 values of $E(T)+10 \log_{10} d$ available for each of two distance ranges, two frequencies, and three percentage values $T=1$ per cent, $T=10$ per cent, $T=50$ per cent. In order to allow for the effects of antenna height, it was assumed that $E(T)+10 \log_{10} d$ is a function of $d_s = d - \sqrt{2h_{te}} - \sqrt{2h_{re}}$. Thus, since $\sqrt{2h_{te}} + \sqrt{2h_{re}} = 39.4$ miles when $h_{te}=500$ feet and $h_{re}=30$ feet, $E(T)+10 \log^{10} d - 10 \log_{10} (d_s+39.4)$ should be related to the distance $d = d_s + 39.4$ for each station.

Analysis of the Ohio mobile data indicates that *any* overland E vs d prediction curves, obtained simply by averaging data, may involve a substantial bias away from estimates appropriate for television allocation. When receiving sites are randomly chosen in hilly terrain, there will be biases in 1) median location, median time fields, 2) variability due to location, and 3) time variability, relative to overland prediction curves determined by averaging data. The effects of these biases may be largely eliminated by using prediction methods appropriate for the specific paths. This has been established for the data in Table I by comparing observed cumulative distributions on the 80 "Ohio mobile paths" with those predicted earlier.[2]

Most available VHF and UHF long term recordings (British, French, German, and U. S.) correspond to unobstructed antenna sites for which the relationship between distance and angular distance is on the average that which would be expected over a smooth earth. At UHF, a small departure from an average smooth earth may result in considerably decreased field strengths.

TABLE I

OHIO MOBILE DATA

Polarization: Horizontal; Receiving Antenna Heights: $h_{re}=30$ Feet

Station	WCOL	WHKC	WCOL	WHKC
Frequency (mc/s)	92.3	98.7	92.3	98.7
Number of Paths	20	20	20	20
Distance Range (statute miles)	76.0–86.7	80.9–88.9	117.7–123.3	119.3–125.7
Height Range of h_{te} (feet)	318–520	619–820	382–547	728–821
Range in hours of observation	87–125	66–186	149–291	120–310
$\bar{d}_s$ (statute miles)	44.32	38.63	83.06	76.61
Range of d_s (statute miles)	40.8–48.1	33.4–42.3	77.4–85.3	71.6–79.3
$\overline{E(50)+10 \log_{10} d}$ (db)	22.3±1.0	26.0±1.0	20.0±0.7	23.6±0.6
$\overline{E(10)+10 \log_{10} d}$ (db)	33.7±1.4	35.6±1.1	29.0±0.8	31.8±0.8
$\overline{E(1)+10 \log_{10} d}$ (db)	>41.6±1.2	>45.2±1.4	>38.5±1.4	>40.0±1.4
Number of Paths with an Uncertain $E(1)$	5	4	4	2
Median of $\{E(1)+10 \log_{10} d\}$ (db)	42.3	45.75	37.1	37.5
s_{50}^2 in db²	20.08	19.78	8.37	6.49
s_{10}^2 in db²	36.98	25.80	11.32	11.43
s_1^2 in db²	29.93	40.37	36.41	36.79

This frequency terrain roughness effect may be accurately accounted for only by methods appropriate for point-to-point prediction using terrain profile information.

In order to make proper use of propagation curves in allocation, it is necessary that a time-fading factor be associated with them. Another paper[2] predicts time variability where terrain profile data is available. A forthcoming report will give estimates of time fading based on antenna heights and distance.[5] Such estimates are presently available in FCC Report T.R.R. 2.4.16, by Fine and Taff.[6]

Fig. 12(a) to 12(g) present empirical estimates of the time-fading factor $E(10)-E(50)$ vs distance and antenna height for each frequency for which a smooth earth $E(50)$ curve is available. The Appendix, written by W. R. Burns, explains how these estimates were obtained from the data. A paragraph at the end of the Appendix indicates how the newer estimates now being prepared differ from those in this report.

The time-fading factors given in Fig. 12(a) through 12(g) are to be applied to the dashed ("best-fit") curves of Fig. 1(b) through 1(f); they do not apply to the smooth earth curves on the same figures. The data show that $E(1)-E(50)$ is very nearly equal to $2[E(10)-E(50)]$ for any distance, antenna height, or frequency; so separate curves of $E(1)-E(50)$ have not been drawn.

In conclusion, the feasibility of tentative television station assignments in particular areas can be established by making proper allowance for the terrain characteristics in the areas under consideration. This determination may be made for each station pair in the proposed allocation by testing it for mutual interference at a selected set of receiving locations suitably chosen within the service areas of the proposed stations by an efficient statistical sampling scheme. This testing may be accomplished by determining the terrain profiles of both the desired and undesired stations from each of the randomly chosen receiving locations and then calculating the two cumulative distributions with time of the transmission losses corresponding to the desired and undesired transmission paths. Using these distributions of transmission loss, it is easy to obtain the expected distribution of the ratio of desired to undesired signals at the terminals of the receiving atenna. The use of these methods will automatically provide allowance for 1) the effects on the expected median field of the actual terrain in the area under consideration, 2) the expected distribution with time of the fields from both the desired and the undesired station, 3) the effect on these time distributions of the particular terrain in the area under consideration, 4) climatological effects in different parts of the country, and 5) the correlation of the desired and the undesired fields with changes in the receiving location. From such an analysis determination can be made of the percentage of receiving locations which should receive a satisfactory signal, but which are expected to be interfered with by the undesired station.

APPENDIX[7]

EMPIRICAL ESTIMATES OF LONG-TERM VARIABILITY

The data selected for this study were CRPL and FCC data, satisfying the two conditions:

1) Measurements of $E(10)$ were selected from data corresponding to the period 6:00 P.M.–midnight, all year, if more than 114 hourly medians or 20 days of data were available, and from period of record data, if the period of record was equal to or greater than one month.

2) Measurements of $E(1)$ were selected from data corresponding to the period 6:00 P.M.–midnight, all year, if more than 240 hours or 40 days of data were available, and from period of record data, if the period of record was equal to or greater than 60 days.

These data were separated into groups by frequency, and the fading ratios $y(10)=E(10)-E(50)$ and $y(1)=E(1)-E(50)$ were computed and plotted vs distance for each frequency group.

Data for which 15 miles $\leq d_s \leq$ 200 miles were classified into the 7 frequency intervals 38–66, 66–88, 88–108, 108–300, 300–500, 500–900, 900–1100 megacycles, and the mean values of $y(1)$, $y(10)$, $\log f_{mc}$ were determined for each interval. These 7 values $\overline{y(1)}$, $\overline{y(10)}$, $\overline{\log f_{mc}}$ were compared with the two-linear function of $\log f_{mc}$ given for $y(10)$ and $y(1)$ by FCC T.R.R.2.4.16[6] for a corresponding set of data $(15 \leq d_s \leq 200)$; the comparison shows somewhat less frequency dependence than is indicated by Fine and Taff.

Data were next separated into the 6 frequency groups 38–88, 88–108, 108–300, 300–500, 500–900, 900–1100 mc. The distance dependence of $y(10)$ and $y(1)$ was determined for distances greater than 100 miles by linear regressions, first using data for all the frequency groups combined. The expressions for $y(10)$ and $y(1)$ so determined were:

$$y(10) = k(10) - (d - 100)b(10) \text{ db}, \quad b(10) = 0.0268 \quad (1)$$

$$y(1) = k(1) - (d - 100)b(1) \text{ db}, \quad b(1) = 0.0480. \quad (2)$$

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[5] P. L. Rice, A. G. Longley and K. A. Norton, "Prediction of tropospheric wave transmission loss and its long-term variability," to be submitted for publication in *J. Res. NBS*, pt. D (Radio Propagation), sometime in 1961.

[6] Harry Fine and John M. Taff, "Propagation Data and Service Calculation Procedures used for the Rescinded Appendix A of Report and Order (Docket 11532) Released June 26, 1956," FCC Rept. T.R.R. 2.4.16; October 22, 1956.

[7] Written by W. R. Burns, National Bureau of Standards, Boulder, Colo.

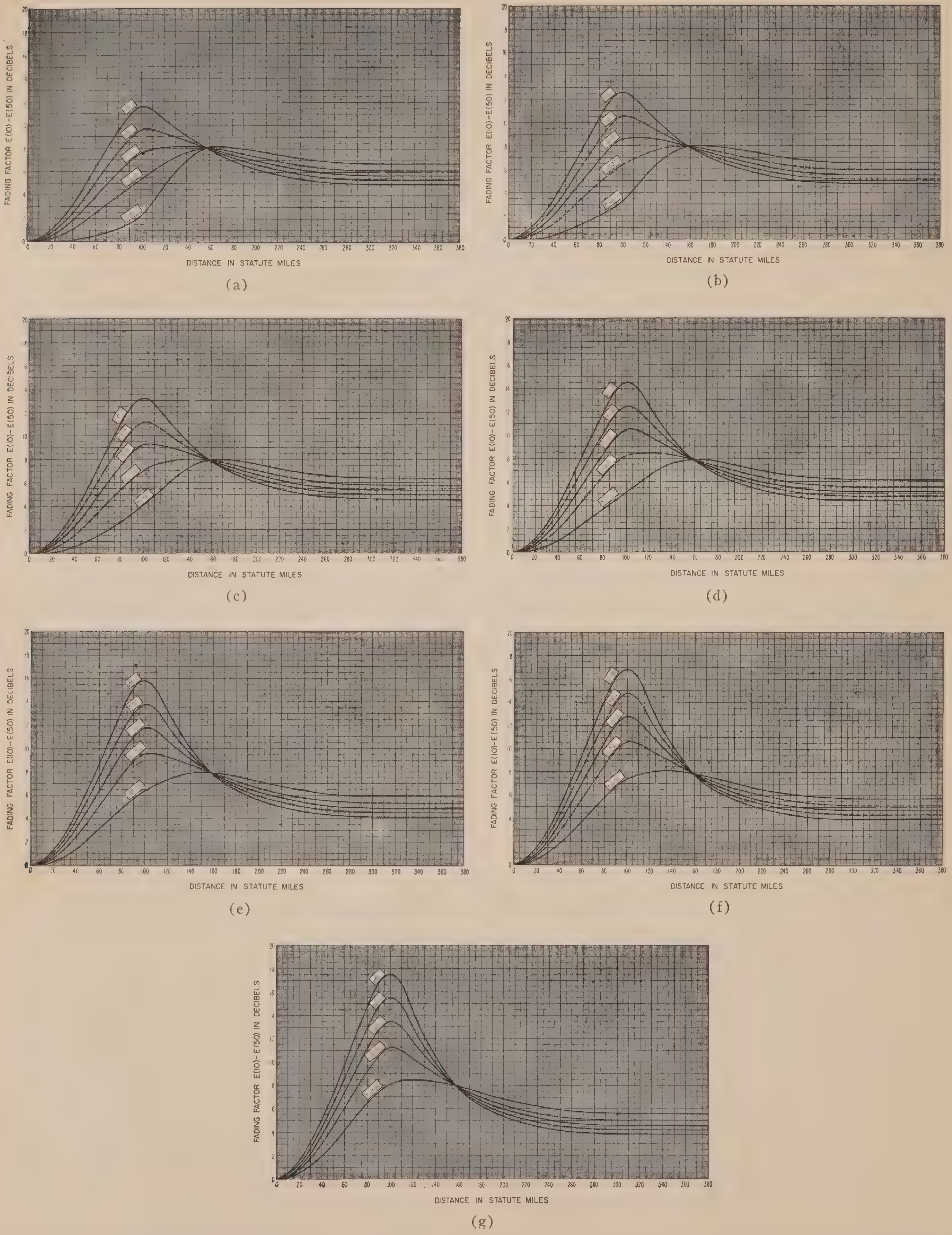

Fig. 12—Long-term fading factor $E(10)-E(50)$ in decibles vs distance and antenna height at (a) 40 mc, (b) 70 mc, (c) 100 mc, (d) 200 mc, (e) 400 mc, (f) 700 mc, (g) 1000 mc. One antenna at 30 feet, the other as indicated. $E(1)-E(50)=2E(10)-E(50)$.

The weighted average of the six values of the ratio $k(1)/k(10)$ for the corresponding six frequency groups, as determined with b fixed, was approximately two. As a check, both k and b were determined separately, for each of three frequency groups.

Next, linear regressions of $k(10)$ and $k(1)$ on $\log f_{mc}$ were found, using the values of $k(10)$ and $k(1)$ for each of the above six frequency groups and the corresponding values of $\log f_{mc}$ for those groups. The expressions for $k(10)$ and $k(1)$ so determined were

$$k(10) = 7.09 + 1.42 \log f_{mc} \qquad (3)$$

$$k(1) = 11.43 + 4.10 \log f_{mc}. \qquad (4)$$

The distance and frequency dependence of $y(10)$ and $y(1)$ for $d<100$ miles was determined as above, except that only the data with low antenna heights—$h_{te} \leq 1000'$ and $h_{re} \leq 50'$—were used. The linear dependence of $y(10)$ and $y(1)$ upon frequency, at $d=50$ miles was compared with earlier work.[6] Also, the comparison was made for $y(10)$ and $y(1)$ at $d=100$ miles. Our determinations still showed a smaller frequency dependence of $y(10)$ and $y(1)$.

For data in the 88–108 mc frequency group with $h_{re} \leq 50'$, $y(10)$ and $y(1)$ were plotted against d, coding for antenna height (see Fig. 13). The curves in Fig. 13 were obtained from Fig. 12(c).

It appears that $y(1)$ is approximately equal to $2y(10)$. The distance dependence of $y(10)$ for $d>100$ miles was originally determined by drawing a curve through median values of data corresponding to overlapping distance intervals; for $d<100$ miles the curve was made to agree closely with the linear regression given by (1). Next, deviations $\delta y(10)$ of $y(10)$ from this curve were calculated for the data in the 88–108 mc frequency group and satisfying the conditions that $h_{re} \leq 50$ feet and $d<100$ miles. A linear regression of δy on $\log h_{te}$ for these data was determined. Also, the median value of d in the range $0<d<100$ miles was found. The same process was carried through for data with $d>100$ miles combined with the data described above.

A plot of δy vs $\log h_{te}$, for $d<100$ miles, $88<f_{mc}<108$ mc, $h_{re} \leq 50$ feet, seemed to indicate that the equation $\delta y(10)=a-b \log h_{te}$, corresponding to this set of data, should be restricted to the interval 200 feet $\leq h_{te} \leq 5000$ feet. A family of $y(10)$ vs d curves was constructed. The different curves of the family were blended together at about $d=160$ miles. It was decided to further restrict the data to be used by the conditions that $h_{te}<2000$ feet if $d<20$ miles and $h_{te}<5000$ feet, if $d<60$ miles; since the above family of curves was constructed using only those data satisfying these conditions. From this family of y vs d curves, a function $b(d)$ was determined and the following formula was now assumed for $y(10)$ and $\frac{1}{2}y(1)$:

$$\frac{1}{2}y(1) = y(10) = a(d) - b(d) \log \frac{h_{te}}{500} + cb(d) \log \frac{f_{mc}}{100}, \qquad (5)$$

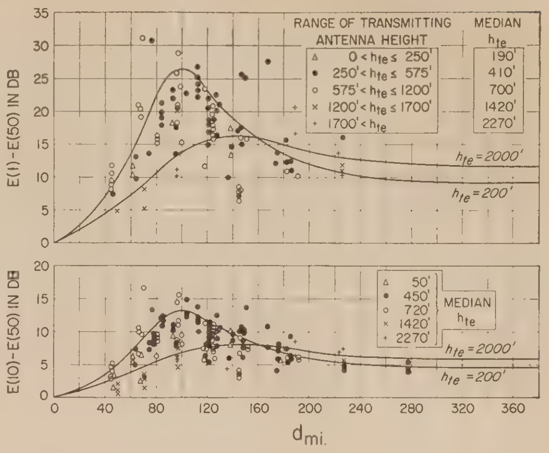

Fig. 13—Long-term variability at 100 mc (88 mc$\leq f_{mc} \leq$108 mc).

After examining how well the data could be made to agree with an empirical function of the form given by (5) and fixing on a value of 0.5 for c, it was decided to take into account the variations of h_{re}, and to use the additional data with $h_{re}>50$ feet, by means of the formula

$$\frac{1}{2}y(1) = y(10)$$

$$= a(d) - b(d) \log \left[\frac{(h_{te}+200)(h_{re}+200)}{(500+200)(30+200)}\right]$$

$$+ b(d) \log \sqrt{f_{mc}/100} \qquad (6)$$

where $a(d)$ is the estimate of $y(10)$ for 100 megacycles and a 500 foot-30 foot antenna height combination. Finally, $b(d)$ was determined by least squares through all of the data available in each of several distance ranges, and the curves in Figs. 12(a) through 12(g) were drawn using graphs of $a(d)$ and $b(d)$ and using the empirical relation (6).

Subsequent work on this problem indicates that at 100 megacycles per second the long-term variability estimates of another paper[2] are better than the TASO estimates for angular distances beyond ten milliradians, and that for smaller distances the TASO estimates are better. Maximum values of y occur where theoretical diffraction and forward scatter fields are equal; it follows that the angular distance at which such a maximum is expected should be inversely proportional to the cube root of the frequency.

ACKNOWLEDGMENT

Most of the organization and descriptive analysis of data, the comparison of data with theory, and the computation of theoretical curves was done by members of the Tropospheric Analysis Section of the Central Radio Propagation Laboratory, under the direct supervision of Mrs. Mary A. Schafer and with the guidance of Mrs. A. G. Longley.

Picture Quality—Procedures for Evaluating Subjective Effects of Interference[*]

GORDON L. FREDENDALL[†], FELLOW, IRE AND WILLIAM L. BEHREND[†], SENIOR MEMBER, IRE

Summary—**In 1958, Panel 6 (Levels of Picture Quality) of the Television Allocations Study Organization conducted a comprehensive study of the subjective effects on picture quality of a number of types of interfering signals and noise, as functions of the levels of interference. These tests were designed and carried out by teams of engineers and experimental psychologists using a selective group of lay observers. This paper deals with the design of the tests and with the laboratory facilities used in the tests.**

THE charge of Panel 6 was stated as follows: "The Panel on Levels of Picture Quality shall determine the numerical specifications of the various objective measures of picture quality which result in specified degrees of subjective viewer satisfaction when television pictures are viewed in the presence of various types of interference."

Television reception is susceptible to interference from many sources which cause degradation of picture quality. Sources which were not considered as relevant in an allocation plan were dismissed by the Panel. Subjective testing was carried out with the following sources of interference: random noise, co-channel interference, upper adjacent channel interference, lower adjacent channel interference, and simultaneous random noise and co-channel interference.

Observations under 63 test conditions were made for monochrome and color reception. A total of approximately 200 observers participated, and 38,000 individual assessments of picture quality were recorded. This paper is intended to present the plan and conduct of the test. The report[1] of the Television Allocations Study Organization to the Federal Communications Commission and the report[2] of Panel 6 should be consulted for a complete account. A résumé of the test data is presented in a companion paper.[3]

Test Personnel and Test Environment

The design of the tests was dictated by the requirement that the test results should be a satisfactory sample of the reaction of the population of home television viewers to pictures accompanied by interference.

The lack of experimental flexibility in private residences with off-the-air signals restricted the choice of a test site to a fixed location at which signal-to-interference ratios could be varied at will and be reproduced. In the opinion of the Panel, the lack of a home atmosphere would be an entirely negligible factor. A large room at the David Sarnoff Research Center of the Radio Corporation of America was selected for the tests.

The plan of the Panel during the early months of activity envisioned the testing of three classes of observers, namely, metropolitan, suburban, and rural, on the basis that individuals from different areas have different criteria as a result of being accustomed to different signal levels and types of interference. As specific test plans developed, it proved impracticable to maintain this distinction. Also, the work already done by Panel 3 indicated that the distinction was probably unnecessary, their experience having been that viewers in unfavorable receiving locations were aware of the poor quality and that judgments of the three classes of observers were substantially alike.

Diversity was exercised in selecting male and female observers with a range of ages from approximately 18–65 years. In all, over 200 observers were recruited from college students and community organizations in the Princeton, N. J. area.

It was concluded that conventional commercial television receivers were the only unquestionably valid display devices for observation by viewers. The question of whether the receivers should be selected from high, medium, or low quality design was resolved by the considered opinion of the Panel that it would be a mistake to use the poorest quality from available models, and that the choice should be made among the higher grade commercial offerings. The selection of five 21-inch receivers, two color and three monochrome, was made by TASO. Placement of the receivers and observers is shown in Figs. 1 and 2.

The average room illumination was 0.6 foot-candle (as reflected from a horizontal magnesium oxide disk) of well-diffused overhead lighting and the highlight screen luminance of the receiver was 20 foot-lamberts.

Test Pictures and Rating Scale for Evaluation of Picture Quality

All television pictures viewed during the tests originated from colored slides. Still subject matter was selected in preference to moving subjects since it is generally acknowledged that observers are less critical of the latter. A television system must be capable of handling the more critical type of subject matter.

A psychological study to determine a scale of picture

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[*] Original manuscript received by the IRE, February 15, 1960.

[†] RCA Labs., Princeton, N. J.

[1] "Engineering Aspects of Television Allocations"; March 16, 1959.

[2] "Report of Panel 6, Levels of Picture Quality"; January, 1959.

[3] C. E. Dean, "Measurements of the subjective effects of interference in television reception," this issue, p. 1035.

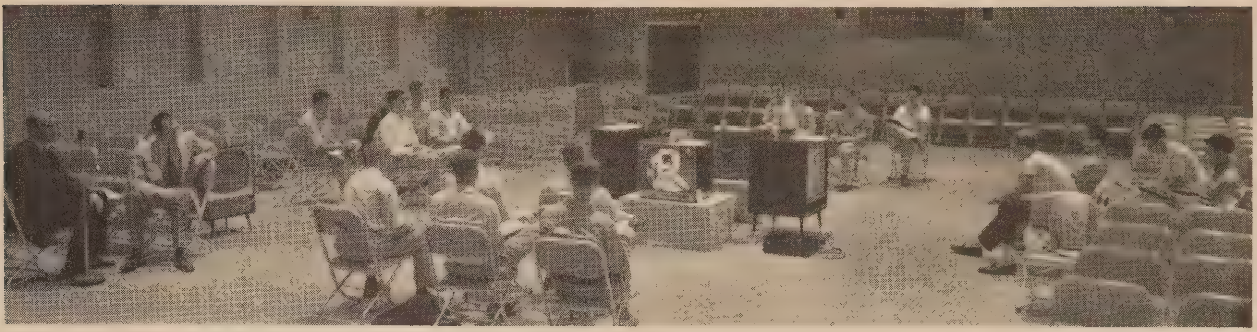


Fig. 1—Viewing room.

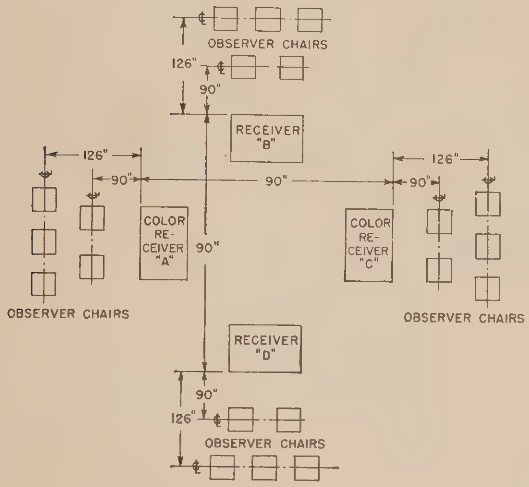
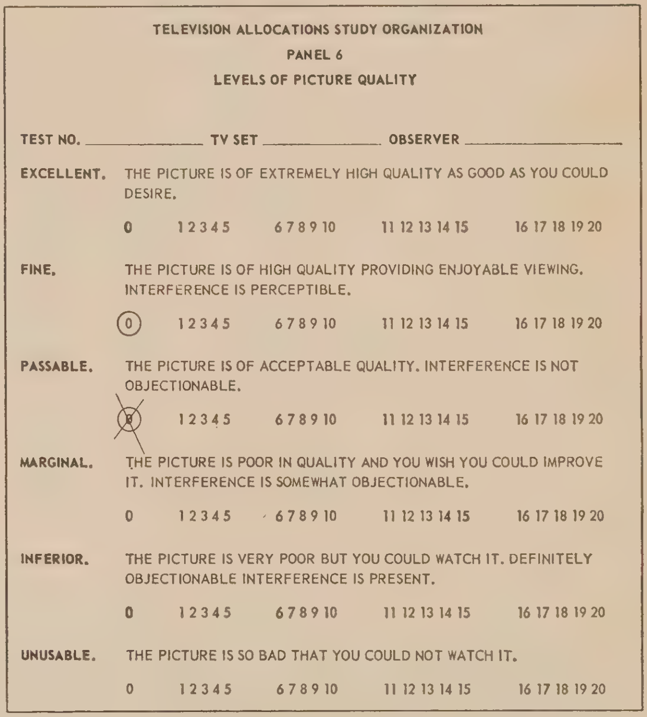


Fig. 2—Viewing arrangement.



TELEVISION ALLOCATIONS STUDY ORGANIZATION
PANEL 6
LEVELS OF PICTURE QUALITY

TEST NO. ______ TV SET ______ OBSERVER ______

EXCELLENT. THE PICTURE IS OF EXTREMELY HIGH QUALITY AS GOOD AS YOU COULD DESIRE.

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

FINE. THE PICTURE IS OF HIGH QUALITY PROVIDING ENJOYABLE VIEWING. INTERFERENCE IS PERCEPTIBLE.

[✓ 0] 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

PASSABLE. THE PICTURE IS OF ACCEPTABLE QUALITY. INTERFERENCE IS NOT OBJECTIONABLE.

~~0~~ 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

MARGINAL. THE PICTURE IS POOR IN QUALITY AND YOU WISH YOU COULD IMPROVE IT. INTERFERENCE IS SOMEWHAT OBJECTIONABLE.

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

INFERIOR. THE PICTURE IS VERY POOR BUT YOU COULD WATCH IT. DEFINITELY OBJECTIONABLE INTERFERENCE IS PRESENT.

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

UNUSABLE. THE PICTURE IS SO BAD THAT YOU COULD NOT WATCH IT.

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

Fig. 3—Observer's scoring sheet.

quality suitable for lay observers resulted in the following scale and word description:

Number	*Name*	*Description*
1	Excellent	The picture is of extremely high quality, as good as you could desire.
2	Fine	The picture is of high quality providing enjoyable viewing. Interference is perceptible.
3	Passable	The picture is of acceptable quality. Interference is not objectionable.
4	Marginal	The picture is poor in quality and you wish you could improve it. Interference is somewhat objectionable.
5	Inferior	The picture is very poor but you could watch it. Definitely objectionable interference is present.
6	Unusable	The picture is so bad that you could not watch it.

This scale and the accompanying definitions were incorporated into the scoring sheet (Fig. 3) on which the observer recorded his impression of each picture.

Conduct of the Tests

A picture accompanied by a certain type of interference was reproduced on each of the four receivers simultaneously for 5 seconds and then removed for 10 seconds to permit rating by the observer on his individual rating sheet before the next presentation was made. Observers were instructed to encircle the number of the presentation under the quality rating dictated by their first impression of the picture. Observers were advised not to vacillate or "reason" in reaching a judgment. Each run consisted of 20 showings of the same subject with 10 different signal-to-interference ratios each repeated 2 times in a random order. The range of ratios extended from severe interference to no interference.

Observers moved as a group to a different receiver at the conclusion of each test run.

Receiver Characteristics

The susceptibility of a receiver to interfering signals on the adjacent channels is determined by the attenuation at the upper adjacent picture carrier and the lower adjacent sound carrier. Attenuation data are given in Table I.

TABLE I

Level in DB Relative to Pix Carrier

Receiver	Pop-up*	Adj. Sound	Band Center	Color Sub-carrier	Sound	Pop-up*	Adj. Pix
1 (color)	−37	<−60	+6	0	<−60	−31	−48
2 (mono)	−33	−51	+5	−1	−22†	−23	−33
3 (color)	−34	<−60	+6	0	−58	−31	−50
4 (mono)	−28	−54	+7	0	−26	−24	−43
5 (mono)	−24	−48	+8	0	−20	−10	−25

* Pop-up refers to the frequency and attenuation at the minimum attenuation point beyond the frequency of the sound trap.

† Sound trap measured −24 but was shifted $\frac{1}{4}$ mc high (at RF).

TV SIGNAL GENERATING APPARATUS

In these simulated transmissions, the FCC requirements for color transmission were observed in all essential respects. A block diagram of the laboratory apparatus is given in Fig. 4 and a photograph of the equipment in Fig. 5. Testing expediency called for duplication of equipment at several points so that the desire of Panel 6 to test one group of observers on a number of different type tests could be fulfilled. Test conditions could be changed for many of the tests within a few minutes.

In all tests, the picture carrier was modulated to place full white at 15 per cent of the sync-tip carrier voltage, and all sound signals were deviated approximately ±7.5 kc at 400 cycles.

The equipment was located in a separate room not visible to the observers. However, there were visual and verbal communications between the equipment operators and the psychologists conducting the tests.

A. Co-Channel Interference

A simplified block diagram of the test apparatus for co-channel interference is given in Fig. 6 (p. 1034). The frequency offsets between the picture carriers were accurately kept by automatic frequency control circuits at the frequencies of reference signals provided by stable oscillators. An oscilloscope monitored the frequency lock and a counter measured the offset frequency.

A resistive distribution system provided identical signals to the monitoring facilities and the receivers. The desired signal was maintained at a constant level, and the level of the interfering signal was varied to provide the signal-interference ratios used for the subjective tests.

B. Random Noise

In the random-noise tests, the noise was combined at RF with a high-level desired signal, as shown in the simplified diagram of Fig. 6. The noise spectrum was flat within ±3 db over TV Channel 4 (66–72 mc); over the more important frequency band, from the picture carrier to the color subcarrier sideband, the spectrum was flat within ±1 db.

Signal-to-interference ratios for various presentations were produced by maintaining the desired signal at a constant level and varying the noise level.

C. Adjacent Channel

Fig. 7 is a simplified diagram of the apparatus for adjacent-channel interference tests. Channel 4 was the desired channel for lower adjacent channel interference and Channel 3 was the desired channel for upper adjacent channel interference.

The frequency response of Channel 4 from the output of the low-power transmitter to the output of the distribution system is given in Fig. 8. Video frequencies in excess of 4.2 mc were strongly attenuated at the input of the transmitter in accordance with standard practice. The filter characteristic is given in Fig. 9.

An attempt was made to operate with the maximum levels of unwanted sidebands allowed by the standards of the Federal Communications Commission. However, it was not feasible to meet this criterion in all cases. The standards state "the lower sideband . . . , shall not be greater than −20 db for a modulating frequency of 1.25 mc or greater and in addition, for color, shall not be greater than −42 db for a modulating frequency of 3.579545 mc (the color subcarrier frequency)." Referring to the response of the interfering upper channel (Fig. 8), it is seen that for modulating frequencies from 1.25 mc to 2.25 mc the lower sidebands were 2 db below the maximum level allowed by the standards. Sidebands due to modulating frequencies greater than 2.25 mc were below the maximum allowable level. However, the energy in these sidebands is small except around the color subcarrier sideband (63.65 mc), where the response is only 1 db less than the maximum allowed by the standards.

The carrier frequencies were measured before each test by a counter which had an accuracy of 3 parts in 10^6. For the lower adjacent channel (Channel 3) interference tests, the receivers were tuned to remove the lower adjacent sound carrier. A different technique was used to tune the receivers for the upper adjacent (Channel 4) interference tests since a well-defined null was not present in all receivers. The receivers were tuned to WRC-TV (Channel 3) and the fine-tuning adjusted for minimum interference from WCBS-TV (Channel 2) sound carrier and picture carrier of WRCA-TV (Channel 4). This procedure insured that the tuning would be correct after restoration of the test carrier signals.

Signal ratios were changed by varying the desired signal level; the interfering signal level remained constant.

D. Simultaneous Co-Channel and Random-Noise Interference

In each of the simultaneous co-channel and random-noise interference tests, the amount of the desired signal and the amount of the random noise were fixed. The interfering co-channel signal was varied over the same range of levels as the levels used for the co-channel interference tests.

The diagram of test apparatus is the same as Fig. 6, except that noise is added to the two television signals at a separate input to the adder.

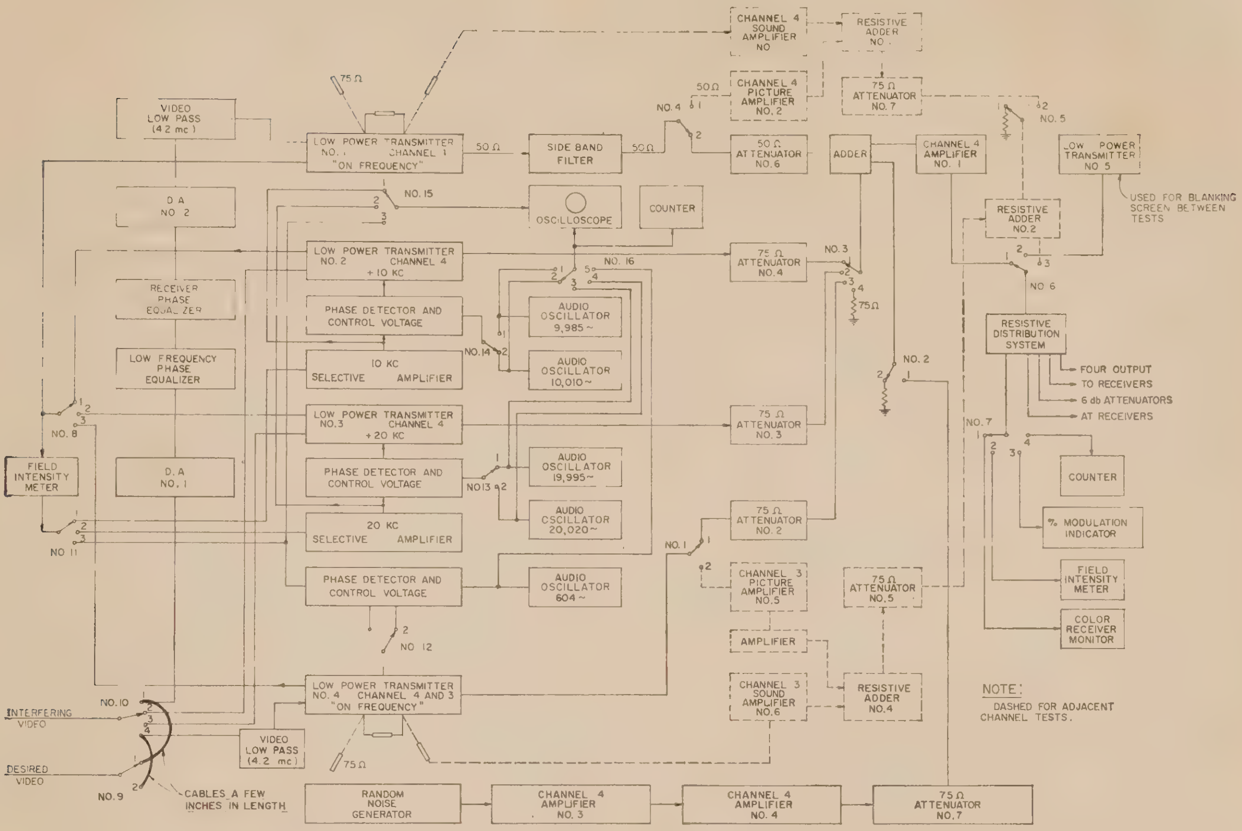

VIDEO LOW PASS (4.2 mc)
75 Ω
LOW POWER TRANSMITTER NO. 1 CHANNEL 1 "ON FREQUENCY"
50 Ω
SIDE BAND FILTER
50 Ω
NO. 4
CHANNEL 4 SOUND AMPLIFIER NO
RESISTIVE ADDER NO.
50 Ω
CHANNEL 4 PICTURE AMPLIFIER NO. 2
75 Ω ATTENUATOR NO. 7
NO. 5
50 Ω ATTENUATOR NO. 6
ADDER
CHANNEL 4 AMPLIFIER NO. 1
LOW POWER TRANSMITTER NO 5
USED FOR BLANKING SCREEN BETWEEN TESTS
D A NO 2
NO. 15
OSCILLOSCOPE
COUNTER
RESISTIVE ADDER NO. 2
LOW POWER TRANSMITTER NO. 2 CHANNEL 4 +10 KC
NO. 16
75 Ω ATTENUATOR NO. 4
NO. 3
NO 6
RECEIVER PHASE EQUALIZER
PHASE DETECTOR AND CONTROL VOLTAGE
AUDIO OSCILLATOR 9,985 ~
75 Ω
RESISTIVE DISTRIBUTION SYSTEM
LOW FREQUENCY PHASE EQUALIZER
NO. 14
10 KC SELECTIVE AMPLIFIER
AUDIO OSCILLATOR 10,010 ~
NO. 2
FOUR OUTPUT
TO RECEIVERS
6 db ATTENUATORS
AT RECEIVERS
NO. 8
LOW POWER TRANSMITTER NO. 3 CHANNEL 4 +20 KC
75 Ω ATTENUATOR NO. 3
NO. 7
FIELD INTENSITY METER
D. A NO. 1
PHASE DETECTOR AND CONTROL VOLTAGE
NO 13
AUDIO OSCILLATOR 19,995 ~
COUNTER
20 KC SELECTIVE AMPLIFIER
AUDIO OSCILLATOR 20,020 ~
75 Ω ATTENUATOR NO. 2
% MODULATION INDICATOR
NO 11
NO. 1
PHASE DETECTOR AND CONTROL VOLTAGE
AUDIO OSCILLATOR 604 ~
CHANNEL 3 PICTURE AMPLIFIER NO. 5
75 Ω ATTENUATOR NO. 5
FIELD INTENSITY METER
COLOR RECEIVER MONITOR
AMPLIFIER
NO 12
LOW POWER TRANSMITTER NO. 4 CHANNEL 4 AND 3 "ON FREQUENCY"
CHANNEL 3 SOUND AMPLIFIER NO. 6
RESISTIVE ADDER NO. 4
NOTE: DASHED FOR ADJACENT CHANNEL TESTS.
NO. 10
INTERFERING VIDEO
VIDEO LOW PASS (4.2 mc)
75 Ω
DESIRED VIDEO
NO. 9
CABLES A FEW INCHES IN LENGTH
RANDOM NOISE GENERATOR
CHANNEL 4 AMPLIFIER NO. 3
CHANNEL 4 AMPLIFIER NO. 4
75 Ω ATTENUATOR NO. 7

Fig. 4—Laboratory apparatus.

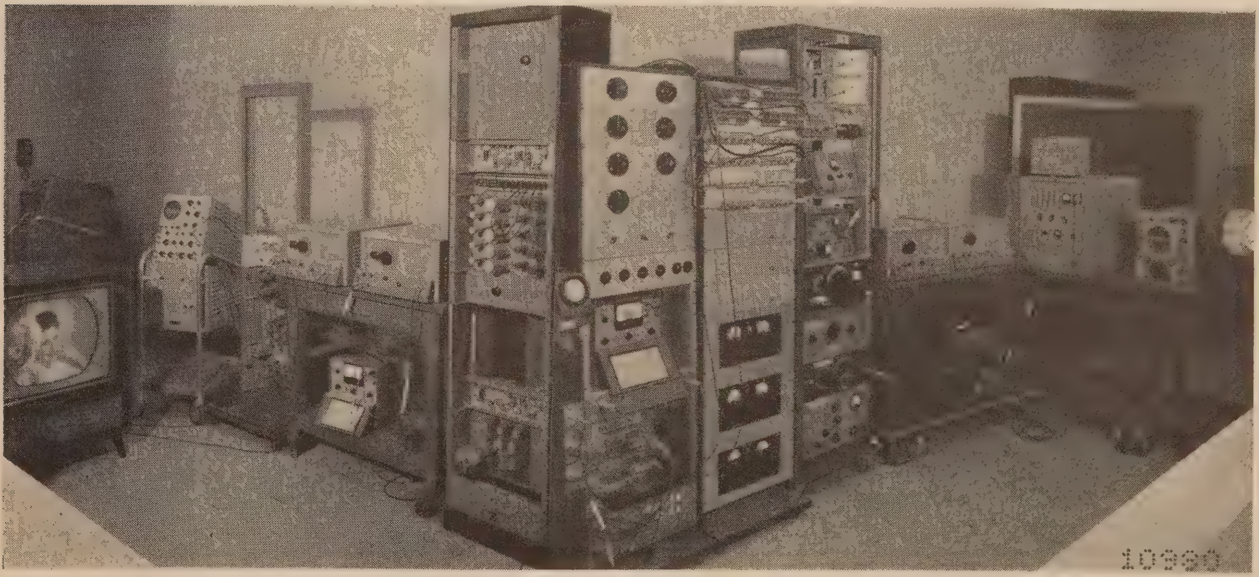


Fig. 5—Equipment setup.

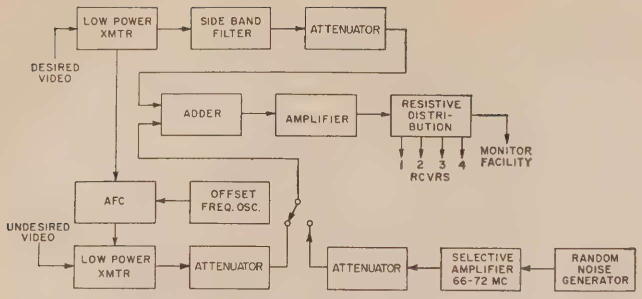

LOW POWER XMTR
SIDE BAND FILTER
ATTENUATOR
DESIRED VIDEO
ADDER
AMPLIFIER
RESISTIVE DISTRI-BUTION
1 2 3 4
RCVRS
MONITOR FACILITY
AFC
OFFSET FREQ. OSC.
UNDESIRED VIDEO
LOW POWER XMTR
ATTENUATOR
ATTENUATOR
SELECTIVE AMPLIFIER 66-72 MC
RANDOM NOISE GENERATOR

Fig. 6—Simplified diagram of co-channel tests and random noise tests.

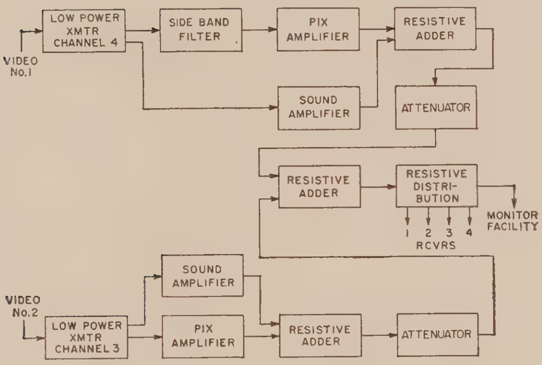

LOW POWER XMTR CHANNEL 4
VIDEO No.1
SIDE BAND FILTER
PIX AMPLIFIER
RESISTIVE ADDER
SOUND AMPLIFIER
ATTENUATOR
RESISTIVE ADDER
RESISTIVE DISTRI-BUTION
1 2 3 4
RCVRS
MONITOR FACILITY
SOUND AMPLIFIER
VIDEO No.2
LOW POWER XMTR CHANNEL 3
PIX AMPLIFIER
RESISTIVE ADDER
ATTENUATOR

Fig. 7—Simplified diagram of adjacent channel tests.

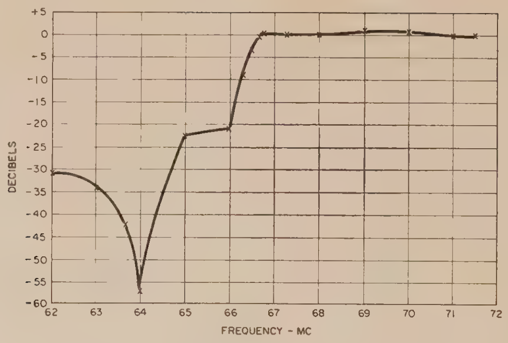


Fig. 8—Channel 4 frequency response.

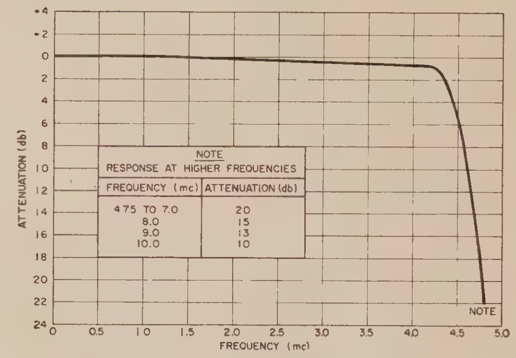


Fig. 9—Amplitude response characteristics of video low pass filter.

Measurements of the Subjective Effects of Interference in Television Reception*

CHARLES E. DEAN†, FELLOW IRE

Summary—**A measurement program was conducted in which almost 200 observers made about 38,000 rating observations on color and monochrome stationary television pictures impaired by various known amounts of interference. Separate tests were made for the following types of interference: upper adjacent channel, lower adjacent channel, random noise, co-channel with each of six carrier-frequency separations, and simultaneous random noise and co-channel. Six rating grades were used as follows: 1) Excellent, 2) Fine, 3) Passable, 4) Marginal, 5) Inferior, and 6) Unusable. The observations were handled on a statistical cumulative frequency basis and plotted on probability paper. Commercial monochrome and color receivers were used, and the tests were made with laboratory signal-generating equipment on the lower VHF television channels.**

As representative results, a picture impaired by upper-adjacent-channel intereference (with 6-mc channels) was rated by 50 per cent of the observers as Passable or better for −27-db ratio of signal to interference. For the lower adjacent case a similar value was found, this result being explained as due to better traps in the medium-high-grade receivers of the test than in many receivers in use by the public. For random-noise interference the requirement for Passable or better rating by 50 per cent of the observers was +27 db on the basis of RMS sync amplitude to RMS noise over the 6-mc channel. The co-channel tests gave the following requirements for the Passable or better rating by 50 per cent of the observers: 22 db for 360 cycles offset, 41 db for 604, 24 db for 9985, 17 db for 10,010, 29 db for 19,995, and 17 db for 20,020. Data for simultaneous co-channel and random-noise interference were taken for 14 combinations of test conditions.

INTRODUCTION

At an early point in the Television Allocations Study Organization (TASO) activity it was realized that the five panels then existing should be supplemented by a sixth, in order to obtain data on the physical qualities of television pictures necessary for given grades of viewer satisfaction. Panel 6 was therefore established and proceeded to plan and carry out a suitable program of experimental tests. The equipment and procedures were chosen with care and are described in the companion paper by Fredendall and Behrend.[1]

The many possible combinations of conditions for which tests could be made, especially when it is realized that more than one type of interference can be present simultaneously, made it desirable to take as many data as possible, but also necessitated that careful selection be made of the conditions to be used. The test program which was carried out consisted of 63 test conditions and included participation by nearly 200 persons, who made about 38,000 individual assessments of picture quality.

The results which are considered of the greatest importance are reported in the present paper, chiefly in the form of plotted curves. A more complete account of the work is included in the general TASO report,[2] and extensive additional data are given in the mimeographed Panel 6 report.[3] The original data sheets, the IBM punched cards to which the original data were transcribed, and tabulations made from the cards, have been forwarded to the Federal Communications Commission, where they are available for any desired future studies.

LIST OF TEST CONDITIONS

The 63 test conditions which were used consisted of 12 with adjacent-channel interference, 8 with random noise, 29 with various types of co-channel interference, and 14 with combinations of co-channel and random-noise interference. All these are listed in Table I, where the general type of interference is shown in the first column. The next column states whether the interfering frame rate was 29.27 or 30 per second, representative of interference from a color or a monochrome transmission. The following columns give the desired picture, the number and sex of the observers, and the identifying test numbers. All tests were performed at Princeton, but the test numbers assigned here were supplemented by additional numbers in the data processing at Rochester, giving the two sets of test numbers in the last two columns.

ACCURACY OF RESULTS

Two methods were used to get information on the accuracy of the results of the tests. The first utilized the fact that numerous individuals made assessments on a picture of given technical quality, so that a standard deviation between individuals was obtainable. The second method utilized the fact that, in most of the tests, there was among the presentations of different signal-to-interference ratios in random order a repetition of each ratio, unknown to the observer, so that a measure was obtained of the consistency with which an observer repeated a previous assessment. The conclusion from these considerations is that the findings from the tests are accurate within a standard deviation of approximately ±1 decibel in the signal-to-interference ratio. This is on the basis of the test procedure consisting of assessments of pictures by the observers without

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* Original manuscript received by the IRE, February 23, 1960; revised manuscript received, March 29, 1960.

† Hazeltine Research Corp., Little Neck, N. Y.

[1] G. L. Fredendall and W. L. Behrend, "Picture quality—procedures for evaluating subjective effects of interference," this issue, p. 1030.

[2] "Engineering Aspects of Television Allocations," TASO Rept. to the Federal Communications Commission; March 16, 1959.

[3] "Levels of Picture Quality," TASO Rept., Panel 6; January, 1959.

TABLE I
Tests Made by TASO Panel 6 in May and June 1958

Type of Interference	Interfering Frame Rate*	Desired Picture	Observers		Test Numbers†	
			No.	Sex	Princeton	Rochester
Adjacent-Channel Tests						
Upper Adjacent Channel	29.97	Miss Taso	18	F	1	1M
Same	29.97	Kitchen	21	F	1K	39J
Same	30	Miss Taso	36	M	1A	2M
Same	30	Kitchen	21	F	1AK	40J
Lower Adjacent Channel (Sound at normal level of 3 db below picture)	29.97	Miss Tsao	18	F	2	3M
Same	29.97	Kitchen	21	F	2K	41J
Same	30	Kitchen	21	F	2AK	43J
Same	30	Miss Taso	18	M	2A	4M
Lower Adjacent Channel (Sound at 10 db below picture)	29.97	Miss Taso	18	F	3	6M
Same	29.97	Kitchen	21	F	3K	42J
Same	30	Miss Taso	18	M	3A	7M
Same	30	Kitchen	21	F	3AK	44J
Random Noise Tests Including Observations with Several Scenes						
Random Noise	Not applicable	Miss Taso	38	F	9	19M
			38	M	9	19M&34J
Same	Not applicable	Cat held by girl	16	F	9C	53J
Same	Not applicable	Drapes and flowers	16	F	9D	52J
Same	Not applicable	Bowl of fruit	16	F	9F	49J
Same	Not applicable	House with horse and carriage	16	F	9H	54J
Same	Not applicable	Kitchen	16	F	9K	48J
Same	Not applicable	Boy & girl holding sail	16	F	9S	50J
Same	Not applicable	Tug of war	16	F	9T	51J
Co-Channel Tests						
Co-channel (604-cycle offset)	30	Miss Taso	18	F	4	9M
Same	30	Kitchen	21	F	4K	45J
Same	29.97	Kitchen	21	F	4AK	46J
Same	29.97	Miss Taso	18	M	4A	10M
Co-channel (360-cycle offset)	29.97	Kitchen	21	F	29K	47J
Co-channel (9985-cycle offset)	30	Miss Taso	38	F	5	11M & 14J
Same	29.97	Miss Taso	18	M	5A	12M
			17	F	5A	2J
Same	30	Kitchen	21	F	5K	16J
			20	M	5K	26J
Same	29.97	Kitchen	17	F	5AK	4J
			20	M	5AK	31J
Co-channel (10,010-cycle offset)	29.97	Miss Taso	33	F	6	13M & 1J
Same	30	Miss Taso	37	F	6A & 6AR	13J & 25J
Same	29.97	Kitchen	17	F	6K	3J
			20	M	6K	30J
Same	30	Kitchen	20	F	6AK	15J
			20	M	6AK	27J
Co-channel (switched between 10,010- and 9985-cycle offset)	29.97	Miss Taso	37	F	14	24M & 5J
Same	29.97	Kitchen	37	F	15	25M & 6J
Same	30	Miss Taso	41	F	18	28M & 17J
Same	30	Kitchen	41	F	19	29M & 18J
Co-channel (19,995-cycle offset)	30	Miss Taso	39	F	7	15M & 23J
Same	29.97	Miss Taso	15	F	7A	11J
			18	M	7A	16M
Same	30	Kitchen	21	F	7K	19J
			20	M	7K	28J
Same	92.97	Kitchen	17	F	7AK	7J
			20	M	7AK	32J
Co-channel (20,020-cycle offset)	92.97	Miss Taso	33	F	8	17M & 12J
			18	M	8	12J
Same	30	Miss Taso	20	F	8A	24J
Same	29.97	Kitchen	17	F	8K	8J
			20	M	8K	33J
Same	30	Kitchen	21	F	8AK	20J
			20	M	8AK	29J
Co-channel (switched between 19,995- and 20,020-cycle offset)	29.97	Miss Taso	37	F	16	26M & 9J
Same	29.97	Kitchen	35	F	17	27M & 10J
Same	30	Miss Taso	41	F	20	30M & 21J
Same	30	Kitchen	41	F	21	31M & 22J

* The two interfering frame rates, 30 and 29.97 cycles per second, give data on the basis of interference coming from a monochrome or color station respectively.

† The K in Princeton test numbers designates the Kitchen Scene. The M in Rochester test numbers designates the May series of tests and similarly J the June series. All tests were made at Princeton, but were assigned separate series of test numbers at Princeton and Rochester.

TABLE I (*continued*)

Type of Interference	Interfering Frame Rate*	Desired Picture	Observers		Test Numbers†	
			No.	Sex	Princeton	Rochester
Tests with Simultaneous Co-channel Interference and Random Noise						
Co-channel and random noise (9985-cycle offset and 38-db ratio of desired signal to random noise)	30	Miss Taso	18	M	11	21M
Same but 32-db ratio of desired signal-to-noise	30	Miss Taso	18	M	10	20M
Same	29.97	Kitchen	20	M	28K	35J
Same but 20-db ratio of desired signal-to-noise	29.97	Miss Taso	18	M	22	32M
Co-channel and random noise (10,010-cycle offset and 38-db ratio of desired signal to random noise)	29.97	Miss Taso	18	M	13	23M
Same but 32-db ratio of desired signal-to-noise	29.97	Miss Taso	18	M	12	22M
Same	29.79	Kitchen	20	M	12K	36J
Same but 20-db ratio of desired signal-to-noise	29.97	Miss Taso	18	M	23	33M
Co-channel and random noise (19,995-cycle offset and 32-db ratio of desired signal-to-noise)	29.97	Miss Taso	18	M	24	34M
Same	29.97	Kitchen	20	M	24K	37J
Same but 20-db ratio of desired signal-to-noise	29.97	Miss Taso	18	M	25	35M
Co-channel and random noise (20,020-cycle offset and 32-db ratio of desired signal-to-noise)	29.97	Miss Taso	18	M	26	36M
Same	29.97	Kitchen	20	M	26K	38J
Same but 20-db ratio of desired signal-to-noise	29.97	Miss Taso	18	M	27	37M

the benefit of any simultaneous comparison. (That is, the tests were not on the basis of comparing two pictures and stating which is better, nor on the basis of one picture being adjustable so that it could be varied to equal the other.)

CHOICE OF SCENE

Preliminary observations by panel members using various scenes produced the impression that the character of the scene had little effect on the assigned ratings. The first main series of tests, made during May, 1958, were therefore mostly with one scene, namely the "Miss TASO" picture shown in Fig. 1. It was then realized that other scenes, especially those where the picture detail is of greater interest than the general effect, might be rated more severely by the observers. In the June tests, therefore, numerous conditions were repeated but with the substitution of the "Kitchen Scene," shown in Fig. 2, where the attention is shared by foliage, grapes, apples, bananas, etc. A comparison of the data revealed that the observers did, in fact, make more severe judgements in the case of the Kitchen Scene to the extent of 0.3 grade, or a spread of ±0.15 grade from the average of the two scenes. (The grade as a unit here is on the basis of the scale of assessment with 1 for Excellent, 2 for Fine, etc., through 6 for Unusable.)

A further study of the effect of scene was made using random-noise interference. Eight of these tests were made, differing only in the change of scene. Included were the scenes of Figs. 1 and 2 and six other assorted scenes. The spread of the assigned grades in the important intermediate range of signal-to-noise ratios averaged 0.6 grade, or ±0.3 grade. The curves for Figs. 1 and 2 were approximately parallel to each other, and were well situated in the center of the total spread. It is considered, therefore, that the bulk of the general data, obtained by averaging the test results with Miss TASO and the Kitchen Scene, is well representative of the range of scenes used in television broadcasting.

In the tests of adjacent-channel and co-channel interference, the picture on the interfering signal was the Sailboat Scene shown in Fig. 3.

EFFECT OF SEX

The 63 test conditions varied with respect to the general type of interference, the interfering frame rate, and the desired scene. Of these 63, a total of 14 test conditions were employed with separate all-men and all-women groups, so that data were available for comparing men and women as television observers. Analysis of the results of these 14 conditions indicated that: 1) women appear to be more critical of technical picture quality to the extent of about 0.3 grade; 2) there is slightly more variation in rating from woman to woman for a given picture than from man to man, the standard deviations being 1.1 and 0.9 grades respectively; and 3) the two sexes are equally consistent in making a second rating on a given picture, the two viewings being in random order among pictures of other signal-to-interference values—the correlation coefficient between the two ratings was 0.80 for both sexes.

This indication that women are slightly more critical viewers is subject to some qualification on account of the fact that about two-thirds of the men tested were undergraduate college students while the women were older, being chiefly members of women's clubs or parent-teacher associations. An age differential and/or a difference in time devoted to television viewing might therefore have influenced the result. However, the result is supported by tests made several years earlier by McIlwain,[4] in which women typically required 390 kc of color video (the signal above this frequency being only mixed highs) while the men required only 320 kc.

On account of the small magnitude of the differences of the data for men and women, and also the practical

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[4] K. McIlwain, "Requisite color bandwidth for simultaneous color-television systems," PROC. IRE, vol. 40, pp. 909–912; August, 1952.

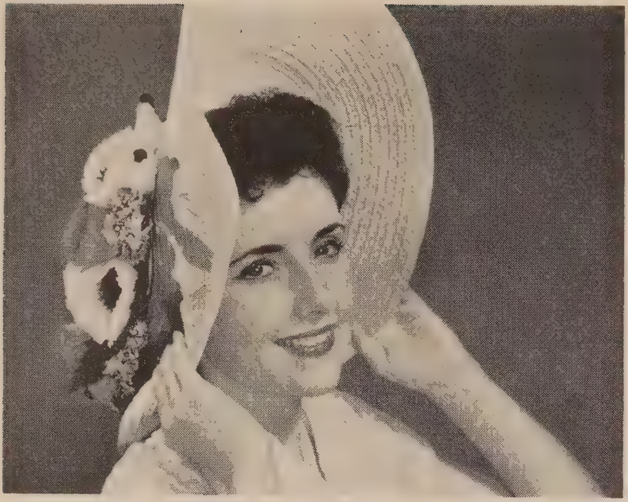

Fig 1—Miss TASO picture used as desired scene in numerous tests.

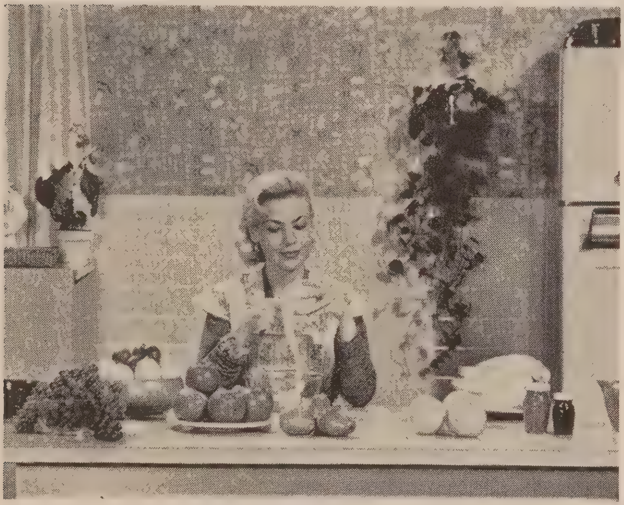

Fig. 2—Kitchen Scene used as alternative desired scene in various tests.

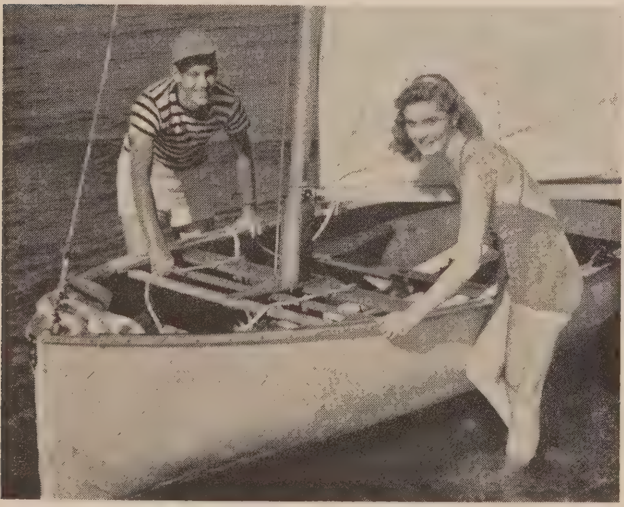

Fig. 3—Sailboat Scene used as interfering scene in adjacent-channel and co-channel tests.

point that television broadcasting is intended for service to the general population, it is considered that this question can normally be disregarded. No adjustment for sex has been applied to the data obtained in the program of tests.

Effect of Frame Rate

The 12 adjacent-channel and the 29 co-channel test conditions were almost equally divided between frame rates of 30 and 29.97 pictures per second, these corresponding respectively to interference from a monochrome and from a color transmission. Comparison of the data for the two frame rates showed that the benefit of precise-offset co-channel operation (at 10,010 or 20,020 cycles rather than 9985 or 19,995 cycles) is somewhat greater when the interference is at 29.97 than when it is at 30 per second. In other tests, frame rate had little effect and it is therefore thought that in allocations matters other than precise offset it will not be an important factor.

Color vs Monochrome

In all tests, the observers were divided into four groups of about five subjects each, two of the groups observing color receivers while the other two observed monochrome receivers. Equal quantities of data were therefore obtained for color and monochrome reception. Comparisons of the data for the two cases have been made in a few instances and revealed little difference, with a suggestion of a slightly greater tolerance for interference when receiving a color picture. The data for color and monochrome reception are therefore pooled in most of the numerous plots giving the Panel findings.

Methods of Data Handling

At least three methods are available for the reduction of data characterized as here by 1) numerous observers, 2) a number of reasonably closely spaced signal-to-interference ratios, and 3) a choice of several merit ratings which have been intended to constitute equal steps of subjective picture quality. Two of the three methods were used in the analysis of the Panel 6 data, and the third has often been used in other studies of this kind.

The first method can be said to employ a cumulative frequency distribution, the term "frequency" being used here in the statisticians' sense of the number of times a particular test value is obtained. With this method, attention is directed to the data obtained with a particular signal-to-interference ratio in a given test and the distribution of ratings by all the observers in the test is determined. With this frequency distribution in hand, the values can then be added up to obtain the cumulative frequency curve (the statisticians' ogive curve). Such data are naturally plotted on a special type of cross-section paper having a "probability scale" in one of the coordinate directions and a linear scale in the other, since on such paper a statistical normal cumulative distribution appears as a straight line and other distributions show more natural shapes than would be the case with other conventional types of plotting paper. The use of this type of data reduction and plotting by Panel 6 was requested by the Federal Communications Commission (FCC); accordingly, plots of this kind were predominantly used. This method is referred to as "Method I."

The second available method of data handling again directs attention to the results for a particular signal-to-interference ratio, but instead of determining the distribution of ratings, it merely includes an averaging of them. This is called "Method II." In comparison with Method I, it has two disadvantages, *viz.*, 1) the grade steps are necessarily assumed equal in Method II, whereas there is no such requirement in Method I, and 2) the original distribution of grades cannot be recovered by going backward from a Method II plot, whereas they can be in Method I. However, Method II has an advantage in that plots made by this method are much more easily understood by lay and semitechnical readers, since the curves clearly show poor grades assigned to low signal-to-interference values and favorable grades to high signal-to-interference values. Various Method II plots are included in the TASO[2] and Panel 6[3] reports, but because of space limitations none are given in the present account.

Method III was not used in the Panel 6 work, but it is listed because it has been used in various investigations heretofore made in this field. This method consists in directing attention to a particular grade of service and then mathematically handling (*e.g.*, averaging) the values of signal-to-interference ratio which the various observers found necessary for this grade of service.

While for some purposes in using the Panel 6 data it may well be unnecessary to give particular attention to the method of data reduction, the reader is cautioned that the different methods do not necessarily give identical results, so that in important applications careful attention should be given to this matter.

Following previous practice of the FCC, the Method I plots of the data have the signal-to-interference ratio on a linear scale of decibels as ordinates and have as abscissas the probability scale indicating the fraction of the viewers assessing the picture to be of a particular grade or better. Five curves are plotted on the sheet, one each for Grades 1 through 5. No sixth curve is shown because 100 per cent of the observers necessarily considered all pictures to be Unusable or better. With the greater signal-to-interference values plotted upward, the Grade 1 (or Excellent) curve is above all the other curves, the Grade 2 (Fine) curve next below, etc. The meaning of any point of any one of these curves is that at the particular signal-to-interference ratio (the ordinate), the indicated percentage of the viewers (the abscissa) rates the picture as of the stated grade or better. Attention may be concentrated, if desired, on values for 50 per cent of the observers, for 90 per cent, or for any other specified percentage.

The cumulative calculation by which these curves on probability paper are obtained may advantageously be described by a simple example. Suppose a picture of a certain signal-to-interference ratio is judged by numerous observers and that the grades assigned are as follows: 5 per cent of the viewers call the picture Excellent (Grade 1), 25 per cent call it Fine (Grade 2), 50 per cent call it Passable (Grade 3), and the remaining 20 per cent call it Marginal (Grade 4). The cumulative operation consists of adding these up, with a result which can be stated as follows: 5 per cent of the viewers call the picture Excellent, 30 per cent call it Fine or better (*i.e.*, Fine or Excellent), 80 per cent call it Passable or better, and 100 per cent call it Marginal or better. These cumulative values are the points on the plotting sheet where the various curves cross the horizontal line corresponding to the signal-to-interference ratio of the picture. In the same way, data for other signal-to-interference ratios are handled and the points plotted, so that sufficient information is obtained to draw in the desired curves. As an example of a Method I plot, see Fig. 4.

In all these plots giving the results of the Panel 6 tests, the plotted points show the data, with the curves drawn in to indicate the general trends.

UPPER-ADJACENT-CHANNEL INTERFERENCE

The desired signal in all tests was according to the FCC color standards, including a frame rate of 29.97 per second. Interference from an upper-adjacent-channel transmission, therefore, appeared as a slowly moving picture if the interference was nominally at 29.97, since the two sync generating chains were independent. If the interfering frame rate was 30 (using 60-cycle power-line synchronization), the interfering picture was completely unsynchronized. The cause of the interference was readily seen to be the picture carrier and sidebands of the upper-adjacent signal, with no effect from the interfering color subcarrier and sidebands or the sound signal.

Plots of the upper-adjacent data, pooling the Miss TASO and Kitchen Scene observations, are shown in Figs. 4 and 5 (p. 1041) for the 29.97 and 30 interfering frame rates, respectively. In the area of chief interest (having grades of Fine (2), Passable (3), and Marginal (4), and 20 per cent to 80 per cent of the observers), the two plots are in good agreement. For the 50 per cent abscissa, as an example of the results, the required signal-to-interference values are −22 db for Fine or better, −27 db for Passable or better, and −31 db for Marginal or better. These values are negative because the receiver selectivity permits the interference to be much stronger than the desired signal at the antenna terminals.

LOWER-ADJACENT-CHANNEL INTERFERENCE

Interference from the lower-adjacent channel appears predominantly as an FM bar pattern of 1.5 mc average frequency, which is the difference between the desired picture carrier and the interfering sound carrier.

Tests of lower-adjacent interference were made with the normal 3-db amplitude relation between sound and picture signals of the interfering transmission, and also with 7 db less sound, that is, with the interfering sound power 10 db below the interfering picture power. The stated signal-to-interference ratios in all cases are the values of desired picture to undesired picture, and are, therefore, on the same basis as the upper-adjacent and the co-channel tests. The lower-adjacent-channel test results are shown in Figs. 6 and 7. It can be seen that the 7-db lowering of the interfering sound signal produced changes of about 5 db in the curves. It may be conjectured that the discrepancy of 2 db indicates the appearance of a small amount of interference due to the lower adjacent color subcarrier.

A comparison of Fig. 4 or 5 with Fig. 6 shows the ratios for upper and lower adjacent interference to be much alike, the requirement for 50 per cent of the observers to assess the picture as Passable or better being −26 db or −27 db in both cases. This varies from the general experience of broadcast engineers, who have normally found interference on the lower-adjacent channel to be more objectionable than interference on the upper-adjacent channel. The present data, showing approximately equal effects, appear to be associated with better traps against the lower-adjacent channel in the receivers used by Panel 6 than are provided in many receivers now in service. The data of Panel 6 were taken with receivers which had lower adjacent sound rejections exceeding their upper-adjacent picture rejections on the average by 14 db. This is substantially different from approximate equality reported by the Receiving Equipment Panel (No. 2) for these two rejection values. The Panel 6 data are therefore considered to be a normal result of the decision of Panel 6 to use medium-high-grade receivers in its test program.

Random-Noise Interference

On account of the unique character of random noise, it was considered of special importance, and tests utilizing five groups of observers, totaling 92 persons, were therefore made. Various scenes were used, as listed in Table I.

The results of these tests are plotted in Figs. 8 and 9. In addition to affording random-noise data, these tests indicated the effect of choice of scene, as already discussed. As representative values of the effect of random noise, 50 per cent of the observers required a 23-db ratio for Marginal or better and a 27-db ratio for Passable or better. The present findings are in general agreement with results found by others.[5–8]

The signal-to-interference ratio in the random-noise tests is the ratio of radio-frequency RMS signal during sync peaks divided by the RMS noise voltage over a 6-mc channel.

Co-Channel Interference

The Panel took special interest in the subject of co-channel interference and conducted numerous tests in this area. Tests were made for various offset frequencies, the Miss TASO and Kitchen Scene pictures, and the two frame rates. In addition, the benefit of precise offset was measured with special accuracy by "switched" tests in which at each observation the offset was changed between the best and the worst, such as from 10,010 cycles (best) to 9985 cycles (worst) in the neighborhood of 10 kilocycles.

The lowest offset frequencies used were 360 and 604 cycles, which are respectively a very good value and a very bad value in the low-frequency range and are representative of the performance which may be obtained with very precise carrier-frequency offset operation.[9] A Method I comparison of the data at these two offsets showed a benefit at the 50 per cent abscissa of about 24 db for Fine, 19 db for Passable, and 13 db for Marginal.

The interference at 360 cycles offset consists of a stationary interfering picture. The data which were taken for this offset consisted of a single test with the 29.97 frame rate and the Kitchen Scene, using 21 female observers. The results are given in Fig. 10. The vertical slopes of the upper portions of the Excellent, Fine and Passable curves here suggest that some pictorial aspects of the picture, such as definition, color rendition, subject matter, etc., influenced the ratings and prevented the assignment of a better grade when the interference was weak or imperceptible.

The 604-cycle offset produces slowly moving, widely spaced, horizontal bars. Data with this offset were taken for the four combinations of the two frame rates and the usual two desired pictures. Pooling these four tests gives the curves in Fig. 11.

Co-channel carrier-frequency offsets of 9985 and 19,995 cycles are two of the more objectionable offsets near 10 kc and 20 kc for the frame rate of 29.97 cycles used for the desired picture. These offsets produce a visual effect of slowly moving, narrow, horizontal bars. These are slightly wider for the 19,995-cycle offset. Offsets of 10,010 and 20,020 cycles are two of the more desirable offsets near 10 kc and 20 kc for a frame rate of 29.97 cycles for the desired picture. A visual interlace effect in these cases leads to a finer bar structure and thus reduces the visibility of the interference. In standard offset operation, the frequency difference may range over an interval of ±1 kc from the nominal separation, passing through favorable and unfavorable pre-

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[5] R. N. Jackson, "Subjective Assessments of Noise in Television Pictures," Mullard Res. Labs., Redhill, Eng., Rept. Np. 308; July, 1959.

[6] L. E. Weaver, "Subjective impairment of television pictures," *Elec. and Radio Engrg.*, vol. 36 pp. 170–179; May, 1959.

[7] T. Kilvington, "Effects of noise in television transmission," *J. TV Soc.*, vol. 9, pp. 26–31; January, 1959.

[8] R. D. A. Maurice, *et al.*, "The Visibility of Noise in Television," BBC Engineering Division Monograph No. 3 Kingswood Warren, Surrey, Eng.; October, 1955.

[9] L. C. Middlekamp, "Reduction of co-channel television interference by very precise offset carrier frequency," IRE TRANS. ON BROADCAST TRANSMISSION SYSTEMS, vol. BTS-12, pp. 5–10; December, 1958.

cise-offset conditions.[10,11] An unfavorable condition may last for an appreciable length of time and therefore is regarded as the determining factor in the grade of station service.

The Panel 6 test conditions, as listed in Table I, included 32 on 10-kc and 20-kc precise offset, covering all combinations of four offsets, two scenes, two frame rates, and two methods of test (direct and switched). Individual plots were made for these 32 combinations and are given in the panel report.[3] Five values read from each of these 32 curve sheets are tabulated in Table II. For the present account the eight plots for 29.97 frames per second and the direct test method seem to be of the most value and are therefore given as Figs. 12 through 19.

Comparing the appropriate values in Table II and pooling the data for the two scenes, we find the benefit of precise offset at 10 kc (*i.e.*, 10,010 cycles vs 9985) to average 7.4 db for the 29.97 frame rate and 4.0 db for the 30 frame rate. Similarly at 20 kc the benefit is 10.6 db for 29.97 and 9.4 db for 30.

Considering only the data for the 29.97 frame rate and the Kitchen Scene, as given in Figs. 13, 15, 17 and 19, and computing separately for the various signal-to-interference values, we obtain the curves of Fig. 20. It is seen that the precise-offset improvement is substantial, especially for the higher grades of picture quality afforded by greater signal-to-interference values.

A comparison for the six offset frequencies of the signal-to-interference values at which 50 per cent of the observers rate the picture as Passable or better is given in Table III and affords a convenient condensed summary of the effect of the various offsets.

SIMULTANEOUS CO-CHANNEL AND RANDOM-NOISE INTERFERENCE

Among the many possible cases of two sources of interference acting simultaneously to impair television reception, the Panel chose that of co-channel interference and random noise as most in need of study because of its importance and the absence of previous research attention.[12] Fourteen test conditions were used, of which two were with a 30-cycle interfering frame rate and the remainder with 29.97. In each test, the amount of the desired signal and the amount of the random noise were fixed. The amount of the interfering co-channel signal was varied over a wide range, and in conjunction with the fixed desired-signal intensity determined the stated and plotted db values of signal-to-interference ratio; *i.e.*, the ordinates do not include the effect of the random noise. In some tests, the amount of random noise was substantial, the ratio of the desired signal to the noise being only 20 db; in other tests, this ratio was 32 db, and in others it was 38 db.

Co-channel and random-noise interference in combination produce a visual effect of narrow horizontal bars moving through a "snowy" picture. The contrast of the bars is proportional to the level of co-channel

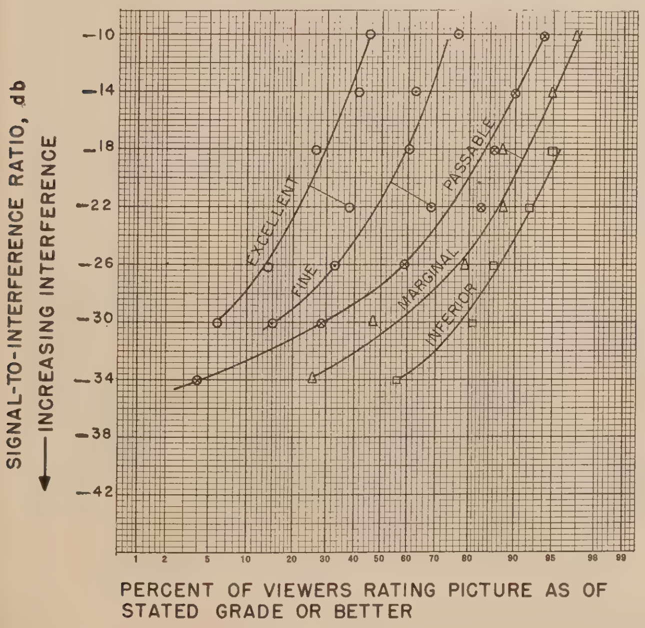

Fig. 4—Upper-adjacent-channel interference with 29.97-cycle interfering frame rate and pooled Miss TASO and Kitchen Scene pictures. Tests 1 (1M) and 1K (39J), using 39 female observers.

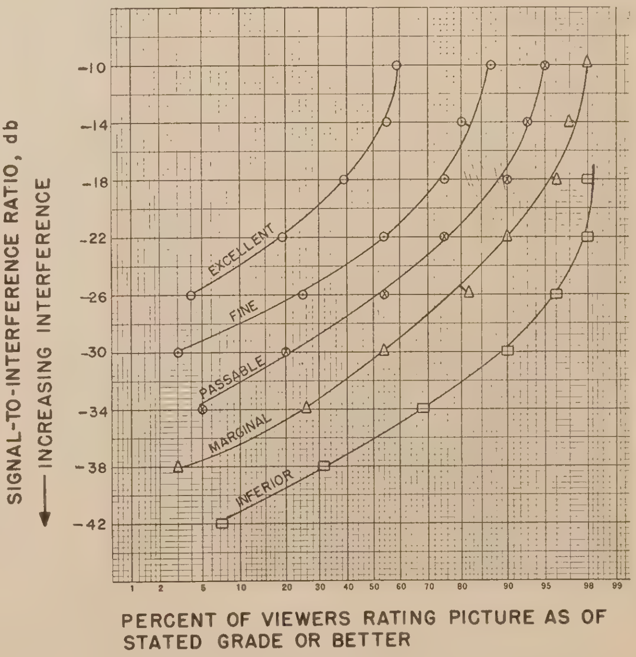

Fig. 5—Same as Fig. 4, but with 30-frame interference. Tests 1A (2M) and 1AK (40J), using 36 male and 21 female observers.

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[10] W. L. Behrend, "Reduction of co-channel interference by precise frequency control of television picture carriers," *RCA Rev.*, vol. 17, pp. 443–459, December, 1956; vol. 20, pp. 349–364, June, 1959.

[11] E. W. Chapin, L. C. Middlekamp and W. K. Roberts, "Co-channel television interference and its reduction," IRE TRANS. ON BROADCAST TRANSMISSION SYSTEMS, vol. BTS-10, pp. 3–24; June, 1958.

[12] "Offset Frequencies for TV Emission: Part III, Multiple Co-channel Interference," FCC Lab. Division, Rept. on Project 222,926; December 13, 1956.

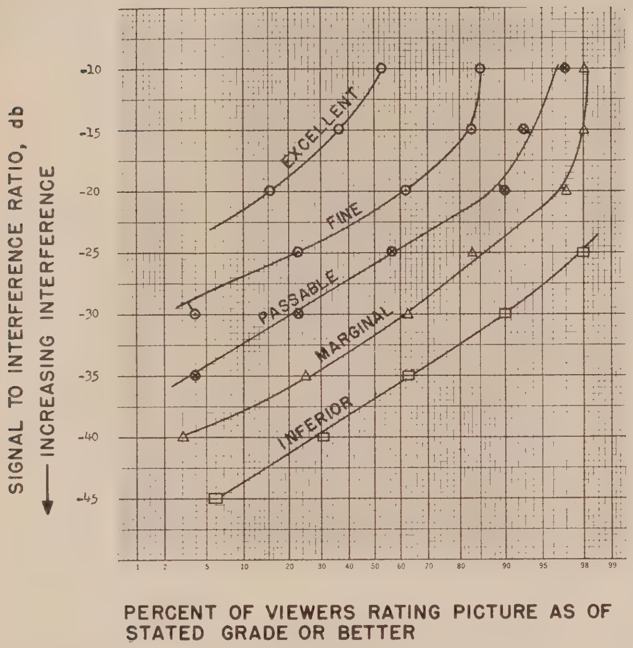

Fig. 6—Lower-adjacent-channel interference with pooled frame rates and pooled Miss TASO and Kitchen Scene pictures. Normal relation of sound and picture power. Tests 2AK (43J), 2A (4M), 2K (41J), and 2 (3M), using 18 male and 60 female observers.

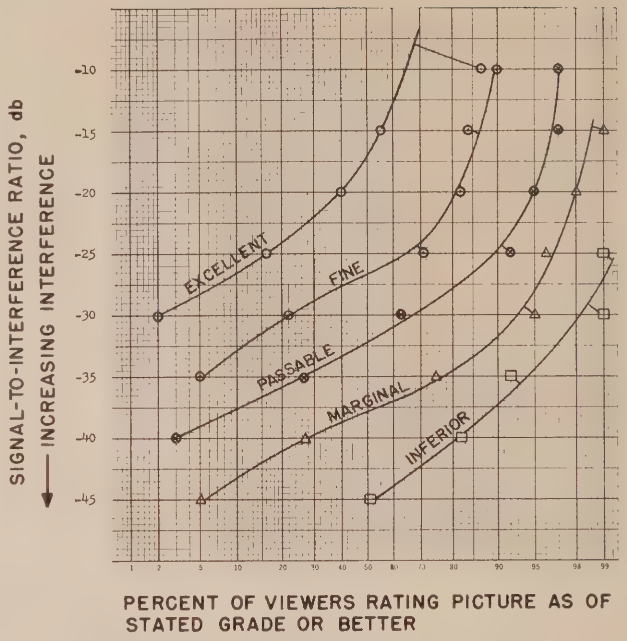

Fig. 7—Same as Fig. 6, but with interfering sound-picture ratio 7 db below normal. Tests 3 (6M), 3K (42J), 3A (7M), and 3 AK (44J), using 18 male and 60 female observers.

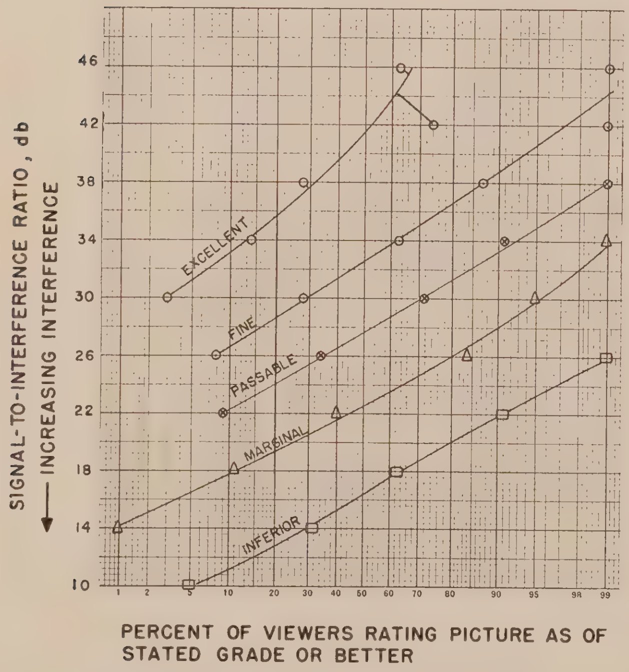

Fig. 8—Random-noise interference with Miss TASO picture. Test 9 (19M and 34J), using 38 male and 38 female observers.

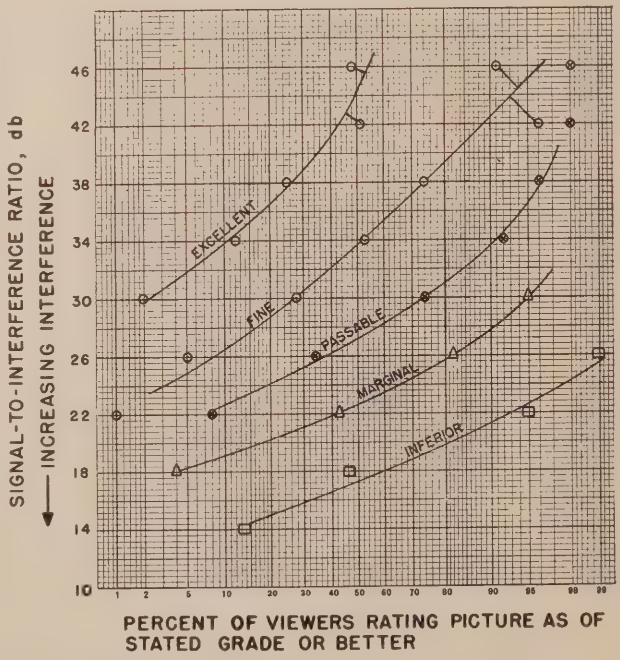

Fig. 9—Random-noise interference, averaging the results from seven scenes not including Miss TASO. Observers were 16 women who participated in all seven tests.

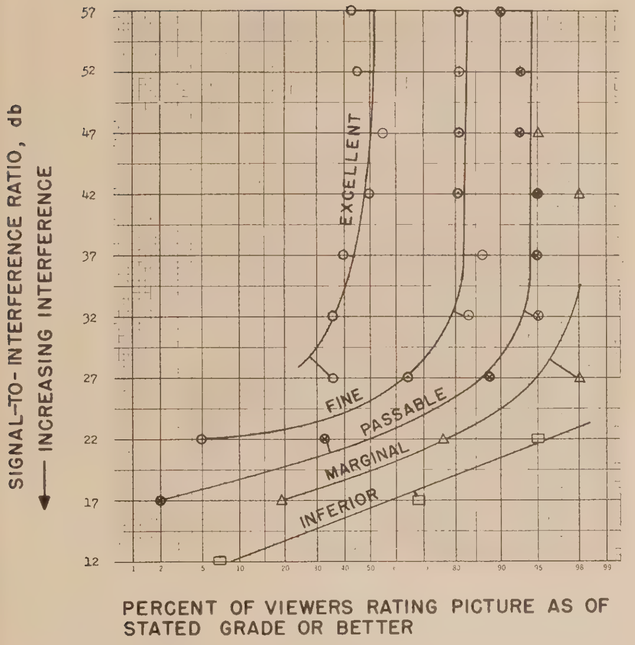

Fig. 10—Co-channel interference with carriers separated by 360 cycles, representative of very precise offset operation. Test was made with 29.97-cycle interfering frame frequency and the Kitchen Scene as the desired picture. The observers were 21 women. Test number 29K (47J).

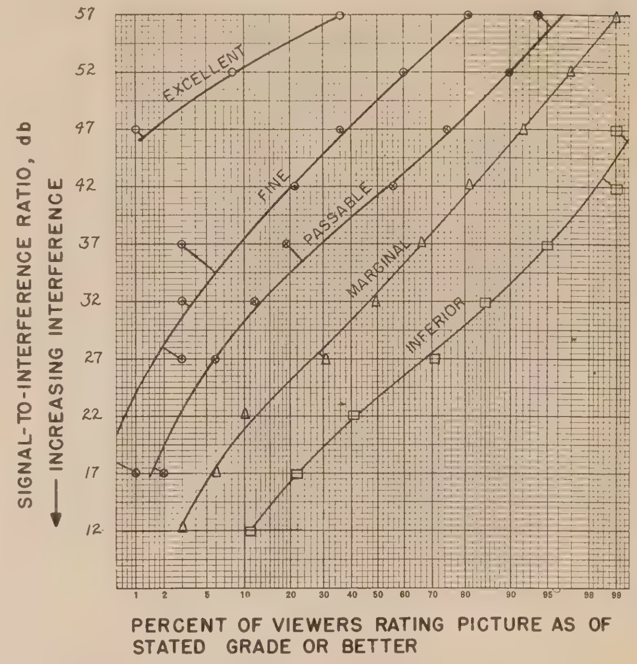

Fig. 11—Co-channel interference with 604-cycle carrier separation, representative of worst relation in region of near-synchronous operation. The data are averages of four tests with the two frame rates and Miss TASO and Kitchen Scene pictures. The observers were 20 men and 58 women. Test numbers 4 (9M), 4K (45J), 4AK (46J), and 4A (10M).

TABLE II

Signal-to-Interference Ratios in Decibels Read from Curves for Co-Channel Intefrerence with Offsets Near 10 and 20 Kilocycles

			Switched 50 Per Cent Passable or Better	Direct 50 Per Cent Passable or Better	Switched 80 Per Cent Passable or Better	Direct 80 Per Cent Passable or Better	Switched 50 Per Cent Fine or Better	Direct 50 Per Cent Fine or Better	Switched 80 Per Cent Fine or Better	Direct 80 Per Cent Fine or Better	Switched 40 Per Cent Excellent	Direct 40 Per Cent Excellent
Offset (cps)	Scene	F. R. (cps)										
9985	TASO	29.97	20.2	21.2	25.0	27.8	28.0	28.1	35.5	33.5	38.5	38.4
9985	Kitch	29.97	25.5	24.0	34.0	31.7	31.5	30.7	41.8	37.3	42.5	38.5
9985	TASO	30	21.8	19.2	25.0	25.3	25.5	24.6	32.0	30.8	34.2	30.6
9985	Kitch	30	24.2	18.2	30.0	23.0	30.3	24.4	37.7	29.6	35.5	32.0
10,010	TASO	29.97	17.8	16.5	21.6	20.3	21.8	22.1	29.0	28.4	25.3	28.5
10,010	Kitch	29.97	19.5	16.6	24.2	21.2	24.2	21.7	31.7	29.4	32.0	33.4
10,010	TASO	30	21.3	17.3	25.7	20.1	22.1	20.7	26.5	24.9	26.8	26.8
10,010	Kitch	30	20.4	18.4	23.5	21.4	25.2	22.1	30.4	25.4	27.7	27.9
19,995	TASO	29.97	25.5	23.1	30.7	28.8	30.8	31.7	37.4	37.4	42.6	41.6
19,995	Kitch	29.97	30.2	29.0	37.2	34.5	35.8	34.2	42.6	41.4	45.7	47.3
19,995	TASO	30	23.6	25.6	28.0	33.7	29.8	34.5	36.2	42.2	41.2	45.8
19,995	Kitch	30	27.4	26.0	31.6	32.4	32.6	32.8	37.4	40.6	39.2	42.9
20,020	TASO	29.97	16.0	16.9	23.0	20.7	23.5	21.3	29.7	25.3	27.2	27.0
20,020	Kitch	29.97	16.0	17.0	23.6	22.5	24.4	22.9	39.6	29.4	42.0	28.5
20,020	TASO	30	19.7	18.6	22.4	21.1	23.8	20.8	26.7	23.1	30.3	30.2
20,020	Kitch	30	23.0	18.1	27.0	22.3	26.6	23.1	30.4	28.5	32.5	29.8

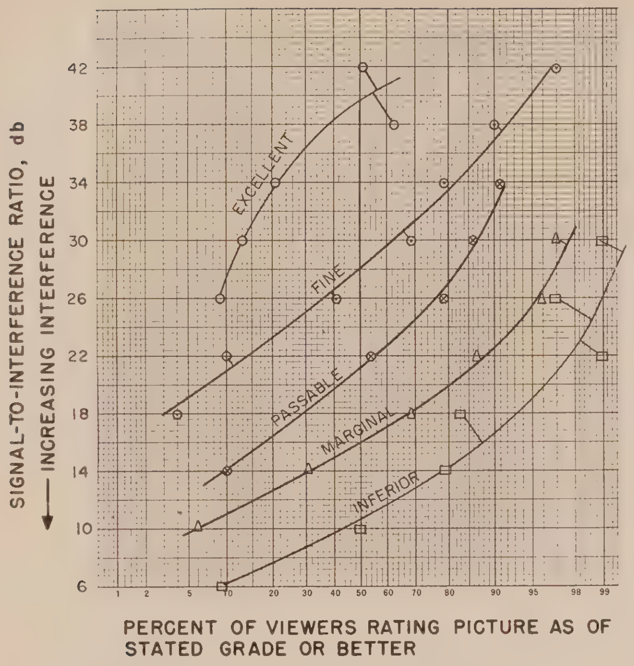

Fig. 12—Co-channel interference with 9985-cycle separation, 29.97 frame rate, and Miss TASO scene. This offset is a very poor one in the vicinity of 10 kc. The observers were 18 men and 17 women. Tests 5A (12M and 2J).

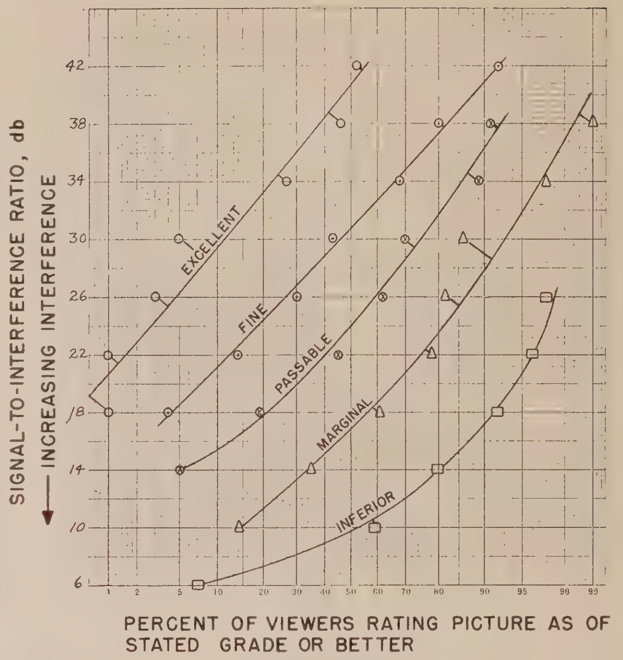

Fig. 13—Co-channel interference for same conditions as Fig. 12 except use of Kitchen Scene. The observers were 20 men and 17 women. Tests 5AK (4J and 31J).

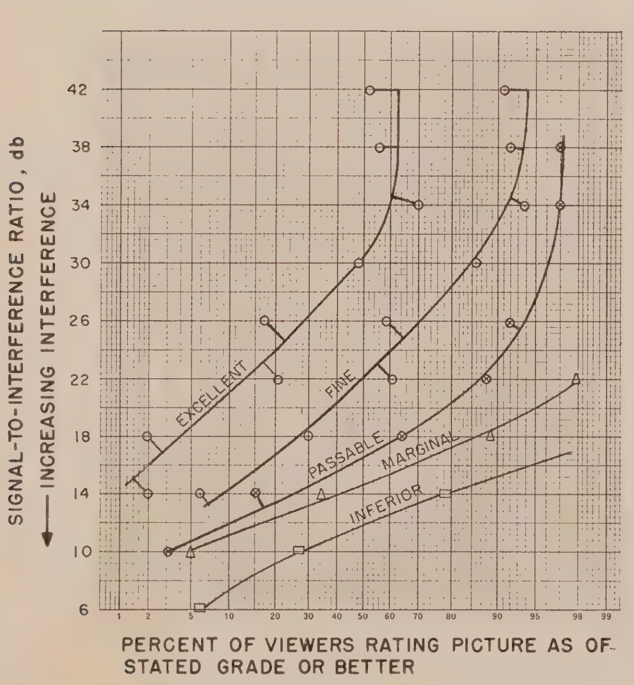

Fig. 14—Co-channel interference with 10,010-cycle separation, 29.97 frame rate, and Miss TASO scene. This offset is a very good one in the vicinity of 10 kc. The observers were 33 women. Tests 6 (13M and 1J).

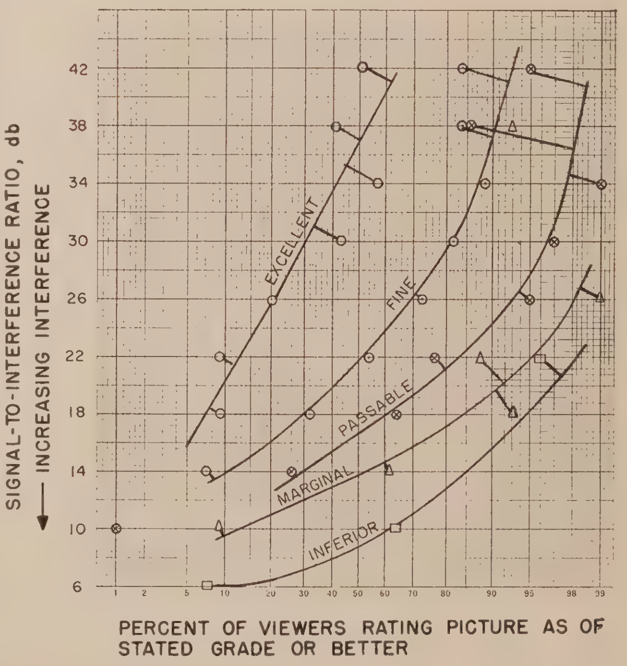

Fig. 15—Co-channel interference for same conditions as Fig. 14 except use of Kitchen Scene. The observers were 20 men and 17 women. Tests 6K (3J and 30J).

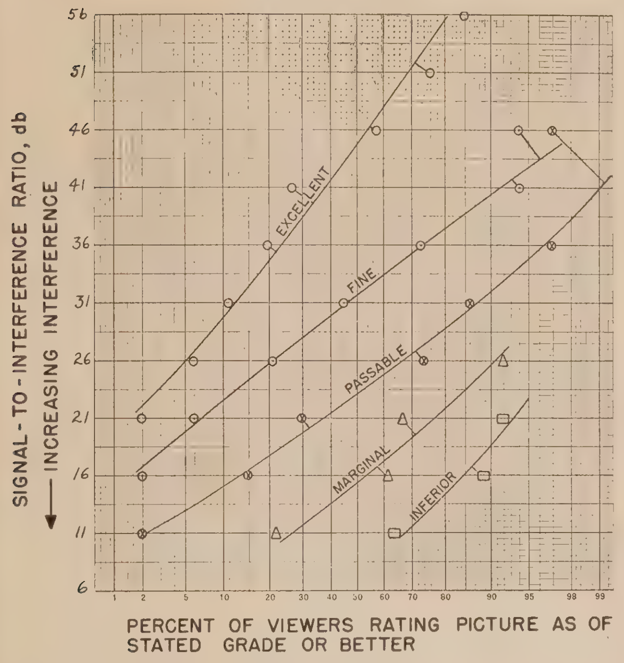

Fig. 16—Co-channel interference with 19,995-cycle separation, 29.97 frame rate, and Miss TASO scene. This offset is a very poor one in the vicinity of 20 kc. The observers were 18 men and 15 women. Tests 7A (16M and 11J).

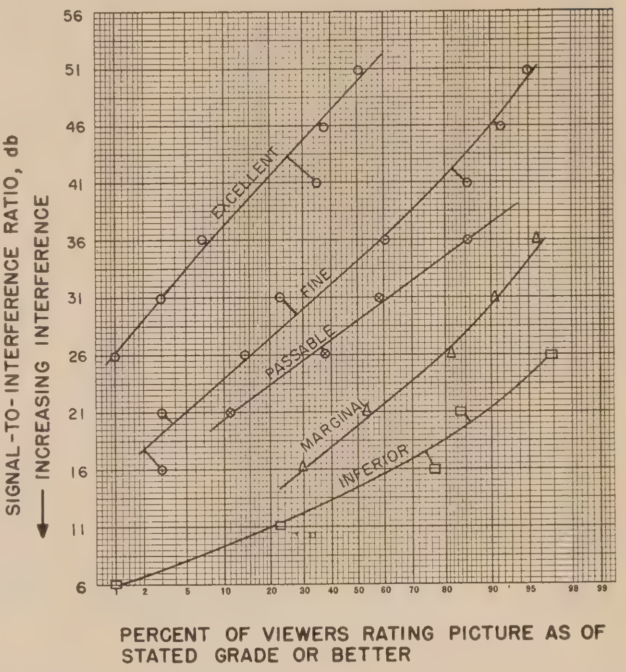

Fig. 17—Co-channel interference for same conditions as Fig. 16 except use of Kitchen Scene. The observers were 20 men and 17 women. Tests 7AK (7J and 32J).

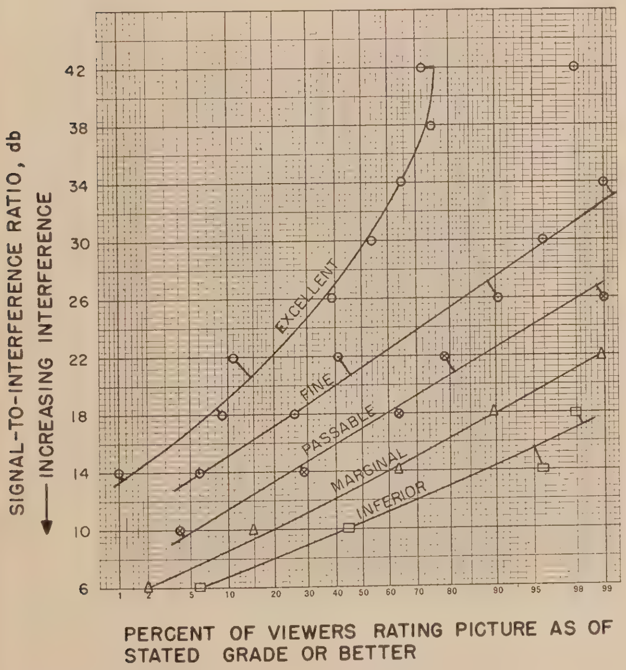

Fig. 18—Co-channel interference with 20,020-cycle separation, 29.97 frame rate, and Miss TASO scene. This offset is a very good one in the vicinity of 20 kc. The observers were 18 men and 33 women. Tests 8 (17M and 12J).

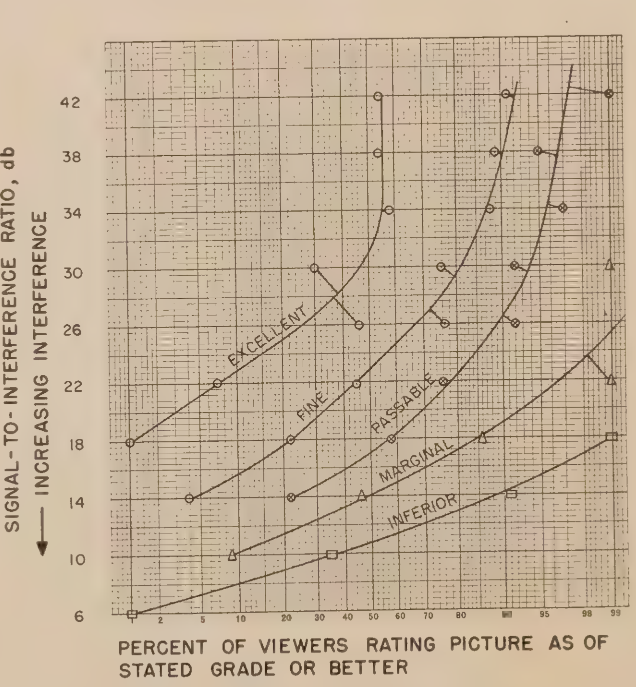

Fig. 19—Co-channel interference for same conditions as Fig. 18 except use of Kitchen Scene. The observers were 20 men and 17 women. Tests 8K (8J and 33J).

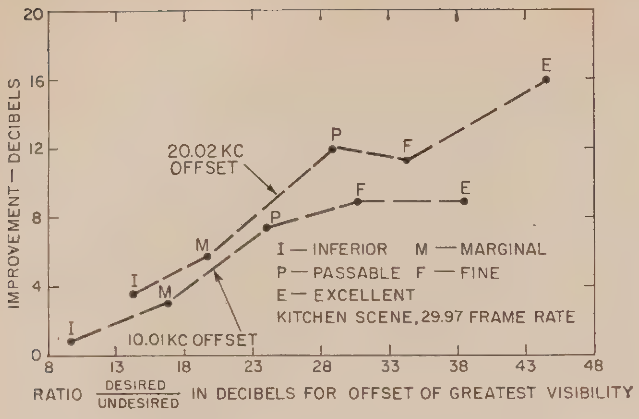

Fig. 20—Improvement afforded by precise-offset operation, computed from Figs. 13, 15, 17 and 19.

interference, and the "snowiness" is proportional to the magnitude of the random noise. The more favorable offsets lead to a finer line structure and reduced visibility of the bar pattern.

It seems likely that in the future considerable effort will be devoted to devising formulas which will give accurately the combined effect of any given amounts of two or more types of interference acting simultaneously. For this reason it appears desirable to give a fairly complete account of the data which the Panel took in this area. The results of the twelve tests at the 29.97 frame rate are therefore shown in Figs. 21–32.

TABLE III

Comparison of Offset Frequencies*

Amount of Carrier Offset	Signal-to-Interference Ratio at which 50 Per Cent of Observers Rate Picture as Passable or Better
360 cycles	22 db
604 cycles	41 db
9985 cycles	24 db
10,010 cycles	17 db
19,995 cycles	29 db
20,020 cycles	17 db

* Conditions: 29.97 frame rate and Kitchen Scene.

An analysis of Figs. 21–32 was made by noting the required signal-to-interference ratios for ratings of Passable or better and Marginal or better and comparing these with the corresponding values for tests with the same types and amounts of co-channel interference but no random noise. In this way, the effect of adding the random noise was obtained. The interesting result was found that in about half the cases the two types of interference (one producing horizontal bars and the other producing general varying mottled effects) seemed to "help" each other, the combination being more acceptable than the co-channel interference alone. This phenomenon was observed in various cases having the 38-db or the 32-db ratio of signal-to-noise, but it was not observed with the greatest noise value corresponding to the 20-db ratio of signal-to-noise.

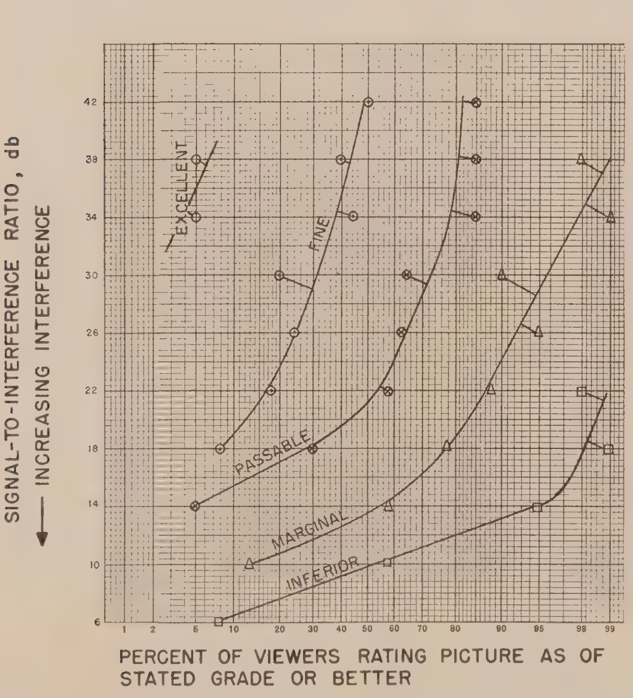

Fig. 21—Simultaneous 9985-cycle co-channel and random-noise interference. The desired signal was at fixed level, 32 db above the fixed random noise. Ordinates give decibel ratio of desired signal to the adjustable-level co-channel interference. Frame rate 29.97 and Kitchen Scene. Observers were 20 men. Test 28K (35J).

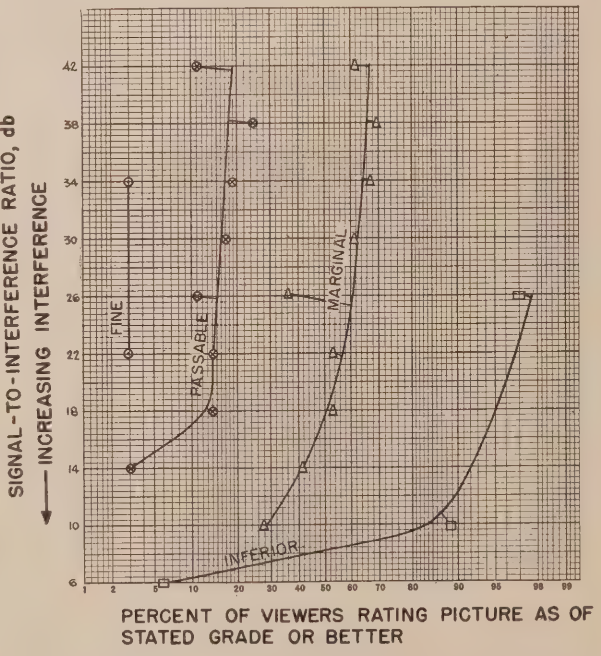

Fig. 22—Same as Fig. 21 except 20-db ratio of desired signal to random noise and use of Miss TASO scene. Observers were 18 men. Test 22 (32M).

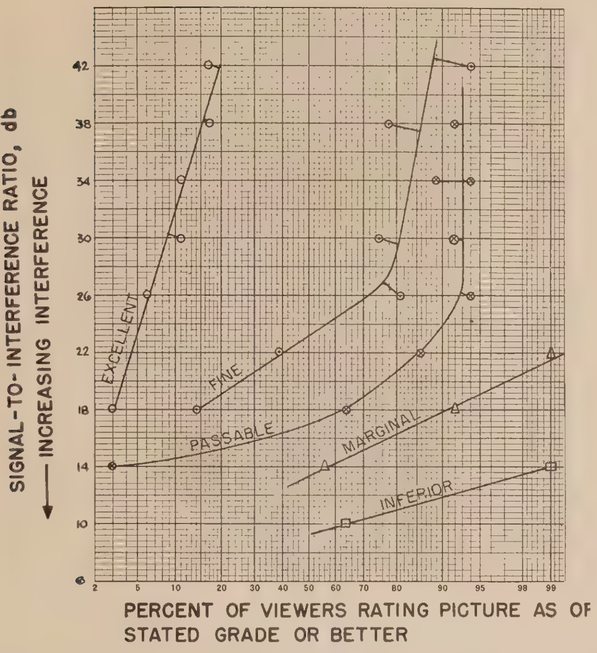

Fig. 23—Simultaneous 10,010-cycle co-channel and random-noise interference with desired signal 38 db above random noise. Frame rate 29.97 and Miss TASO scene. Observers were 18 men. Test 13 (23M).

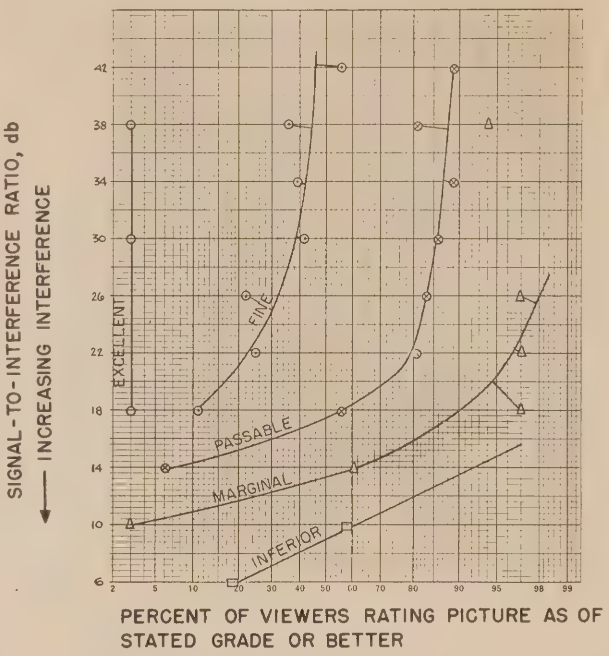

Fig. 24—Same as Fig. 23 except desired signal 32 db above random noise. Observers were 18 men. Test 12 (22M).

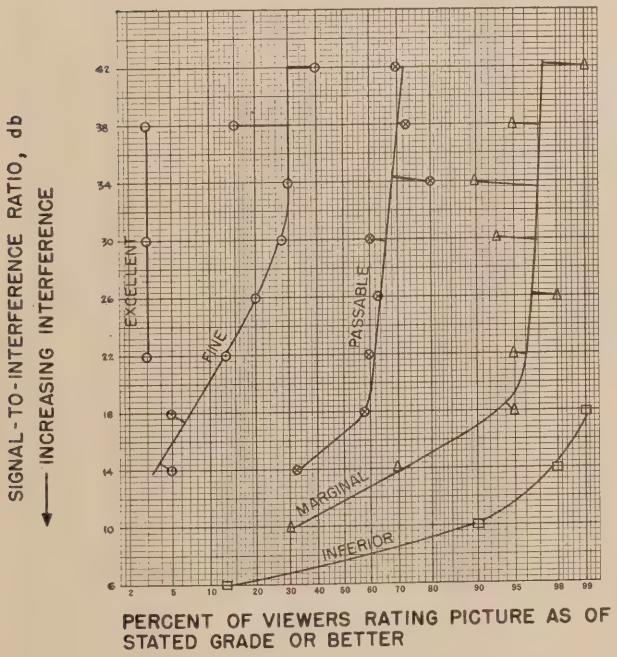

Fig. 25—Same as Fig. 24 except Kitchen Scene. Observers were 20 men. Test 12K (36J).

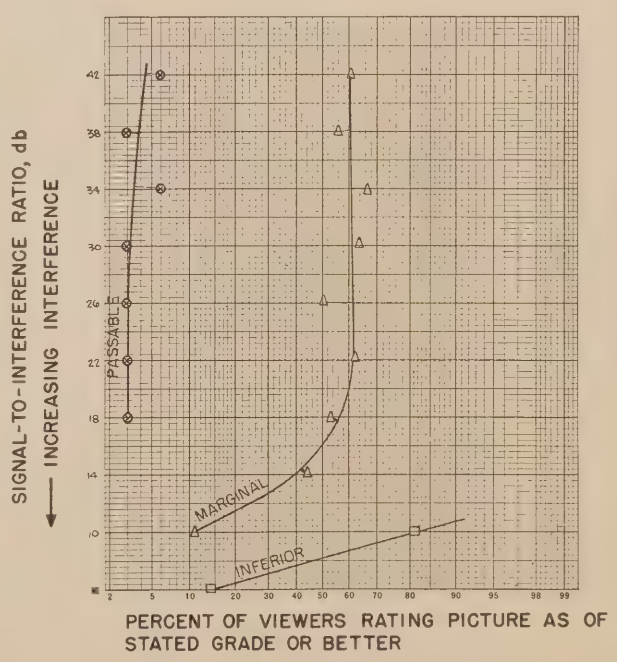

Fig. 26—Same as Figs. 23 and 24 except desired signal 20 db above random noise. Observers were 18 men. Test 23 (33M).

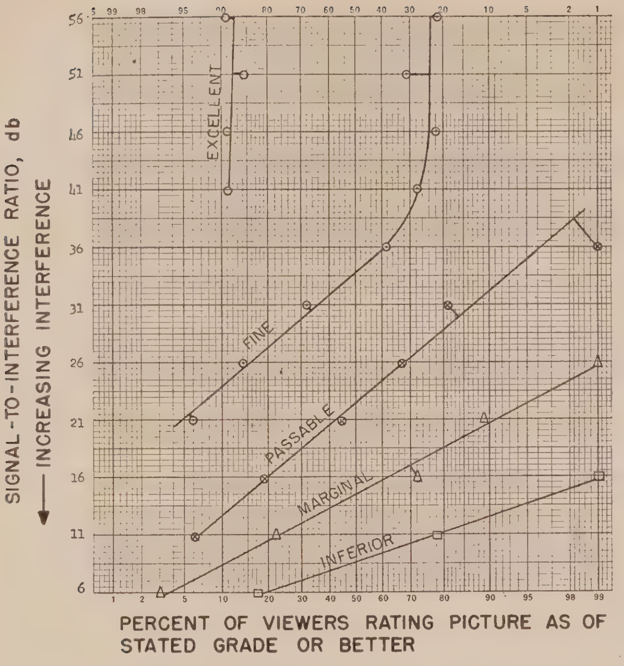

Fig. 27—Simultaneous 19,995-cycle co-channel and random-noise interference with desired signal 32 db above random noise. Frame rate 29.97 and Miss TASO scene. Observers were 18 men. Test 24 (34M).

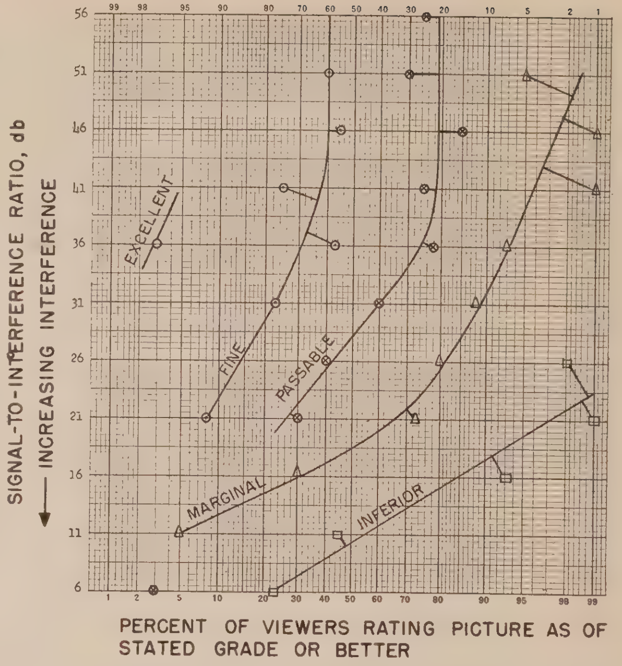

Fig. 28—Same as Fig. 27 except use of Kitchen Scene. Observers were 20 men. Test 24K (37J).

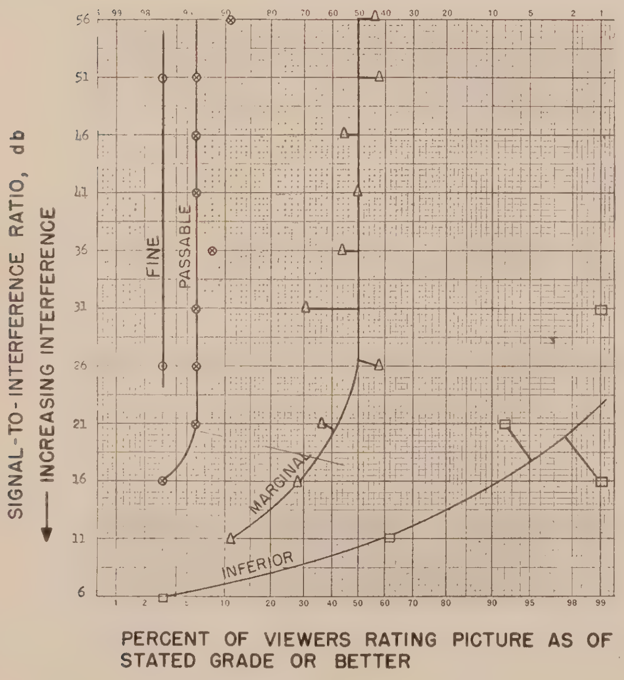

Fig. 29—Same as Fig. 27 except desired signal 20 db above random noise. Observers were 18 men. Test 25 (35M).

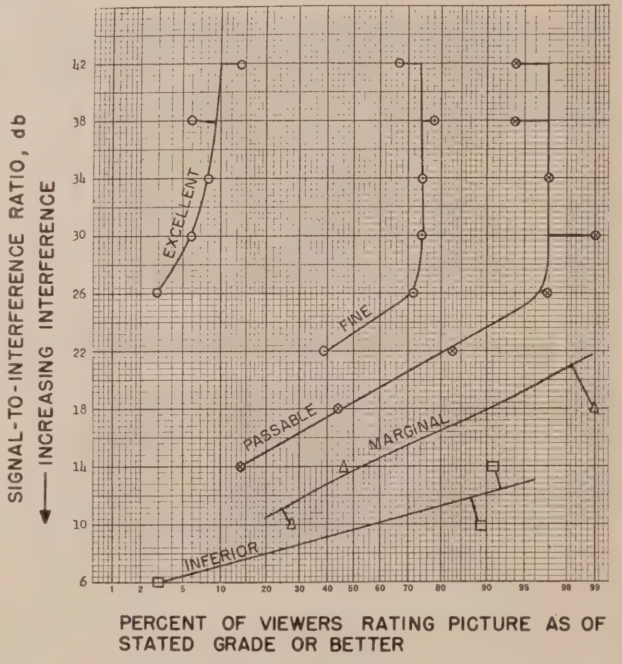

Fig. 30—Simultaneous 20,020-cycle co-channel and random-noise interference with desired signal 32 db above random noise. Frame rate 29.97 and Miss TASO scene. Observers were 18 men. Test 26 (36M).

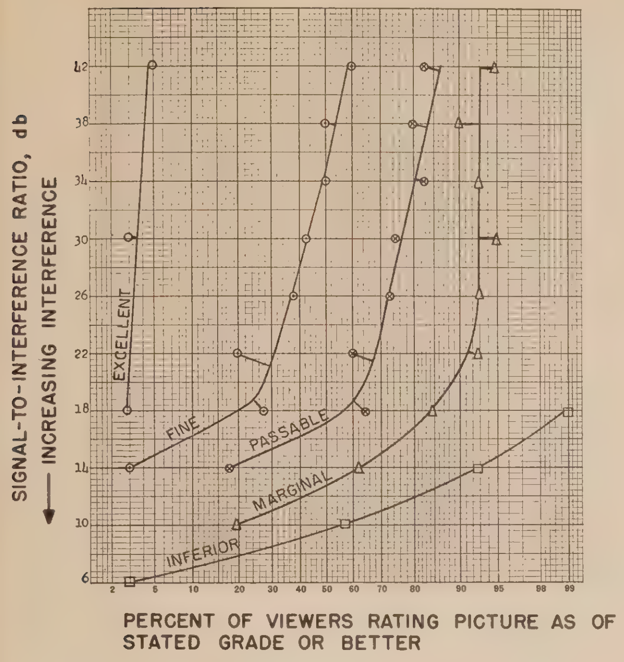

Fig. 31—Same as Fig. 30 except use of Kitchen Scene. Observers were 20 men. Test 26K (38J).

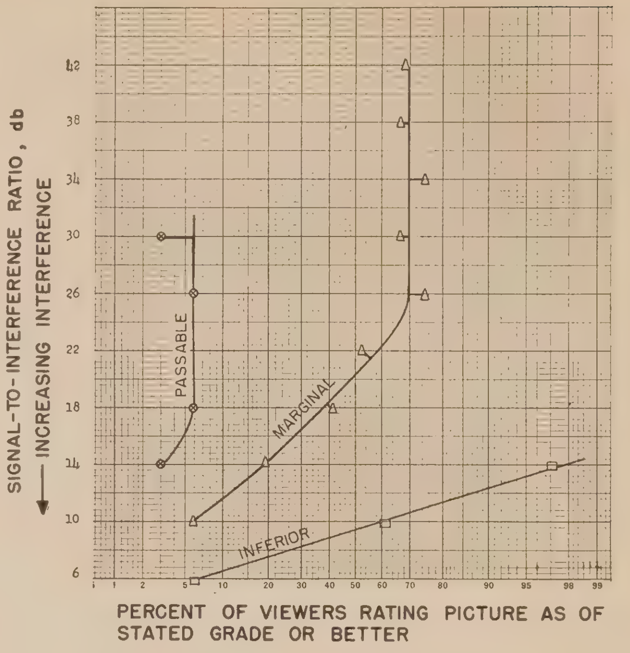

Fig. 32—Same as Fig. 30 except desired signal 20 db above random noise. Observers were 18 men. Test 27 (37M).

UTILIZATION OF THE DATA

The Panel gave a broad interpretation to the scope of its duties in that several grades of viewer satisfaction were taken into consideration and determinations were made of the physical television-picture characteristics necessary for each grade. In particular, six grades were chosen, so that the tests yielded data in terms of these grades or ratings. On the individual subject's scoring sheet these were given as the choices among which each observer selected in making each observation. These six grades, already given, were 1) Excellent, 2) Fine, 3) Passable, 4) Marginal, 5) Inferior, and 6) Unusable.

In utilizing the Panel data, therefore, a direct method is to choose the grade of service to be taken as a criterion, and then to consult the detailed Panel findings for the signal-to-interference ratio required. Should uncertainty be felt in choosing the grade of interest, reference should be made to the sentence descriptions of the six grades given on the observers' data sheets and available in the companion paper.[1] Weight should also be given to the scale used by Panel 3 in the field tests, and by the NTSC in 1950–53, since the Panel 6 scale was designed to be the same except for names and definitions better suited for tests involving the lay public.

When the grade to be taken as the criterion for service has been chosen, the data of Panel 6 are available for determining the required signal-to-interference ratio for various types of interference.

The data of the Panel can also be used in the opposite direction, *i.e.*, to determine for assumed conditions of signal and interference what degree of viewer satisfaction would be experienced.

A study of the Panel 6 data has been made recently by H. Fine of the Federal Communications Commission, including new proposed methods of application. It is expected that this work will be published in the near future.

One aspect of the Panel 6 tests, which should be of value, is that they afford results on various types of interference taken under fairly closely comparable conditions. For example, the question can be answered as to how much random-noise interference is equivalent to a given amount of upper-adjacent-channel interference.

It should be emphasized that extensive analyses of the data beyond those performed by the Panel are possible and should give useful conclusions. This seems a fertile field for doctoral research by graduate students. The original observers' data sheets, the punched IBM cards, and machine-made tabulations are being preserved by the Federal Communications Commission so as to be available for further study.

ACKNOWLEDGMENT

The author especially wishes to acknowledge the interest and the contributions of time and ideas by the members, alternates, and observers of Panel 6. It is regretted that these individuals were so numerous that it is impractical to list them here.

The author also acknowledges the support of the various organizations represented was invaluable. Notable among these were the David Sarnoff Research Center, RCA, Princeton, N. J., and the Eastman Kodak Company, Rochester, N. Y.

Studies of Correlation Between Picture Quality and Field Strength in the United States*

C. M. BRAUM†, SENIOR MEMBER, IRE AND W. L. HUGHES‡, MEMBER, IRE

Summary—**The purpose of this paper is to present data which correlate a given level of picture quality with some corresponding level of measured field strength. The data were gathered by actual house-to-house surveys in conjunction with field strength measurements. This procedure was followed rather than making laboratory tests on new receivers because it was desired to evaluate coverage as it actually was, not as it ought to be. Particular attention was paid to differences between UHF and VHF channels with respect to receiver and antenna performance in given field strengths. The ranges of field strengths required for a passable picture quality are fairly well established for each band of television channels.**

BACKGROUND

FOR many years, the accepted procedure for arriving at television coverage has been to make field strength measurements in the prospective coverage area of a given television station. These measurements were then coupled with assumed performances of the average home receiver and antenna installation to arrive at some scale of television service coverage. It is necessary to point out that no quarrel is taken with this method. Ultimately, for any given station or market, it is the only foreseeable method that will continue to be used. The difficulty with this approach thus far is that there are many factors which, if ignored, may cause the method to give false conclusions. It is probably expedient to point out some of these factors.

1) The effects of multipath are not accounted for in field strength readings. In turn, this will determine the nature of the antenna installation required for a good television picture. Inherent in this problem is the question about the effort and expense to which people will go to eliminate undesirable ghosts, and how bad such ghosts need to be before they become subjectively important.
2) The evaluation of variations between the performance of receivers of different types and sensitivities, and perhaps what is more important, the degradation of receiver performance with age.
3) The effects of variation in the quality of antenna installations, and the rate of performance deterioration of the antenna installation with weathering and age.
4) The effects of rough terrain as opposed to smooth terrain on signal strength and standing wave patterns within the structure of the general field distribution.
5) The effects of foliage and seasonal variations on propagation, and therefore on picture quality and uniformity throughout the year.
6) The effects of short term variation of weather conditions on picture quality and uniformity. This is of interest not only because of propagation effects, but also because of the equally important factor of degradation of average receiver antenna performance when the antennas and lead-ins are wet and dirty.
7) The effects on service degradation occurring because the receiver owner does not operate his set properly.
8) The effects of the competence level of servicemen.

It goes without saying that all of the above factors vary with the frequency of transmission, be it VHF or UHF. This factor must be considered critically in all of the difficulties listed. It has seemed to some qualified individuals that to evaluate the effects of all of these difficulties is a hopeless task. It is certainly hopeless if one tries to separate and assign numbers to all of the factors by means of objective measurements alone. It does not follow, however, that objective aggregate information on all of the factors cannot be obtained by a combination of objective field strength measurements and subjective house-to-house surveys on over-all picture quality for representative television service areas over the nation.[1] This was the attack taken by Committee 3.3, of which the authors of this paper were co-chairmen, at the direction of the Television Allocations Study Organization (TASO), Panel 3, on field tests. Once such information is obtained, it can be correlated to find not only aggregate effects but also some individual effects of the degrading factors listed.

PROCEDURE OF THE SURVEYS

The fundamental problem of evaluating the aforementioned factors in television coverage might be restated in a manner which more properly describes the tests which were made. This problem was to correlate

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* Original manuscript received by the IRE, February 1, 1960.

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[1] Early work in this area was done by Raymond F. Guy of the National Broadcasting Company. See R. F. Guy, "Investigation of ultra high frequency television transmission and reception in the Bridgeport, Connecticut area," *RCA Rev.*, pp. 98–142; March, 1951. Direct comparisons between Mr. Guy's work and the work of Committee 3.3 are difficult to make because of different data-taking procedures, but such comparisons show no apparent inconsistencies.

picture quality observed in an area with field strength readings taken in that area. Such a correlation study provides the aggregate effects. In addition, certain questions were asked at each home to assist in separating the aggregate effects into some of their component parts. The surveys were made in different types of terrain and in locations all over the country. Surveys were made in the following general areas:

1) Baton Rouge, La.,
2) Madison, Wis.,
3) Albany, Schenectady, and Troy, N. Y.,
4) Fresno, Calif.,
5) Bakersfield, Calif.,
6) Columbia, S. C.,
7) Harrisburg, Pa.,
8) Connecticut Valley Area, New England,
9) Buffalo, N. Y.,
10) New Orleans, La.,
11) Northern Minnesota Area.

All but two of these areas were chosen because of their primary television service. At the time the survey came from both UHF and VHF, so that direct comparisons were possible. The two exceptions were Northern Minnesota and the Albany-Schenectady-Troy area. No facilities were available for simultaneous measurement of the UHF and VHF at Albany-Schenectady-Troy. Therefore, UHF only was measured. Minnesota was chosen as the last test area because it had become apparent that more data were needed for rather weak VHF television signals. Three of the areas have essentially smooth terrain (Baton Rouge, New Orleans, and Columbia). One combined area (Fresno and Bakersfield) has terrain which represents both the smoothest (San Joaquin Valley) and the roughest (Sierra Mountains) terrain that was surveyed. Three of the areas have moderately smooth terrain with a certain amount of rolling hills (Madison, Buffalo, and Minnesota). Three of the areas have moderately rough terrain but not as rough as the Sierras (Albany-Schenectady-Troy, Connecticut Valley, and Harrisburg).

In each area surveyed, station wagons were equipped with field measuring equipment and trained operating personnel. The equipment used on each survey was owned by one of the following: Association of Maximum Service Telecasters, the CBS Television Network, the Federal Communications Commission, or Jansky and Bailey, Inc. personnel to make the house-to-house surveys were provided by the participating television stations in each area. In every case the house survey team was composed of competent television technicians or engineers. At the beginning of each study, the Chairman or Co-chairman of TASO Committee 3.3 visited the area to instruct the survey crew, and to spend a few days in the field with them. Each house survey team was made up of at least two men. Except for two cases, at least one of the men was from a VHF station and one was from a UHF station. This arrangement was deliberate, to avoid unconscious bias factors in the answers. It is the opinion of these authors, at least, that the dual arrangement was probably necessary for the avoidance of later criticism, but that the quality and integrity of the men in the survey teams was such that no bias would have been introduced except in perhaps a negative manner. It was never necessary to restrain a man from boosting his own station, but on occasion it was necessary to insist that each man make his ratings as objective as possible, and that he not lean over backwards in favor of another station.

The field test procedure was uniform throughout the country. Two types of general surveys were run. These two types will be termed *urban clusters* and *rural arcs.* In the urban cluster type of survey, a series of up to thirteen points was chosen in a given measurement location covering an area of approximately one square mile. Urban areas of varying population density were chosen at distances ranging fron five to one hundred and twenty miles from the transmitters of interest. These urban areas were scattered around the transmitter locations as evenly as was possible and consistent with the requirement that all major types of terrain in the area were to be sampled. Further, it was attempted to lay out the geometric pattern of the measurement points in any given urban measurement location in such a way that local terrain variations and urban characteristics were all represented, *i.e.*, river bottoms, hill tops, plateaus, business districts, residential districts, etc. The rural arcs were laid out on topographic maps in such a way that measurement points were approximately equidistant from the transmitters and were separated from each other by two or three miles. In this way it was possible to obtain information that was of use to Committee 3.3 while simultaneously gathering propagation information for other TASO panels.

The general procedure at individual measurement points was as follows. At each point, field strength readings were made on two (or in one case three) calibrating stations. Except for the Minnesota and Albany-Schenectady-Troy surveys, one of the calibrating stations was a major VHF station in the area, and the other was a major UHF station in the same area. Field strength measurements were made at ten and thirty feet for both visual and aural carriers of each calibrating station. In addition, field strength readings of visual and aural carriers were made (at thirty feet only) for other stations which were received in the area. In many cases, continuous ten-foot recordings of field strength were made at both UHF and VHF along the routes covered by the survey teams.

The questions asked of the householder are given on the survey sheet of Fig. 1. It will be noted that this sheet is simply a tabulation of the type of questions raised at the beginning of this paper. The rating of picture quality was carried out with the six point scale common to the NTSC testing programs carried out some years ago. The six possible ratings were *Excellent*, *Good*, *Passable*, *Not Quite Passable*, *Poor*, and *Not Usable*. The index column on the survey sheet is really the column for the engineer's rating of picture quality. It was not expedient to put the engineer's opinion in one column and the owner's opinion in another column, particularly if they did not agree, and the owner happened to see the survey sheet. Therefore, the engineer's opinion was coded. After carrying out the survey one or two times, the engineer's opinion was recorded after leaving the house, so this piece of subterfuge was probably not as necessary as was first thought.

The receiver was always operated by the householder. The survey teams were specifically instructed not to touch the receiver. Each member of the survey team had a special identification card, and a mimeographed letter of thanks on a TASO letterhead was given to each householder on the departure of the survey team. These arrangements and precautions were apparently sufficient because little difficulty was experienced in getting into the house for individual surveys.

Eleven surveys were run in all. There were an average of perhaps nine measurement locations per survey, each requiring a full day, and an average of eleven interviews

CONFIDENTIAL—FOR USE OF FIELD TEST PANEL—CONFIDENTIAL
TELEVISION ALLOCATIONS STUDY ORGANIZATION
Questionnaire for UHF/VHF Television Reception Study

Date ____________ Time ____________ Weather ____________

Location ____________

Description of Site (urban, rolling country, hill top, etc.) ____________

____

Name of Receiver Owner ____________ Address ____________

ANTENNA

Channel	Height	Age	Orientation	Type

TRANSMISSION LINE

VHF ____________ UHF ____________ Separate (yes or no) ____________

RECEIVER

Type and size of receiver ____________ Age of receiver ____________ When last service call ____________

TUNER

Type of tuner ____________ Separate converter (yes or no) ____________

RELATIVE PICTURE QUANLITY

Channel	Index	Owner's Opinion	Comments

OTHER COMMENTS

____

____

Who operated receiver? ____________ Engineer's name ____________

Fig. 1.

per measurement location, making a total of around 1100 interviews. There was an average of about three measurements of field strength per measurement point, and there were usually one or two more measurements than interviews in a given location, so the number of individual measurements is in excess of 3500. Since there were about five men involved in each survey (at least two interviewers, a driver, the measuring engineer and often a TASO member), the effort expended equals well over one and a half man years. This includes field work only. It does not include time for panel and committee meetings and data analysis.

Presentation of Data

One of the major objectives of this program was to obtain correlation information between field strength and picture quality that could be later used by the FCC for channel allocations purposes. As such, it would seem that a point-by-point correlation of picture quality and field strength on some sort of graph would be in order. This type of data analysis was attempted on both an individual point and a statistical basis, but was found to be useless for reasons that were obvious after several areas were surveyed. The combination of variability in receiver performance plus the effects of standing wave patterns in the field strength distribution made it unreasonable to expect a good point-by-point correlation. A more reasonable and more productive approach proved to be to plot the median field strength for a given measurement location against the median picture quality observed in that location. The picture quality rating was obtained by averaging the opinions of the householders and the engineers making the survey. The average difference between the nationwide householder and engineer opinions was 0.43 point on the six point scale, the engineers' opinion usually being lower than that of the householder's. Positive and negative differences averaged out to some extent, and thus in the aggregate, the engineers' opinion averaged only 0.13 point lower than that of the householder. Fig. 2 is a plot of all the median data. Each point represents the median field strength (visual carrier at 30 feet only) vs the median picture quality for one mesaurement location (*i.e.*, the medians of some ten or twelve observations). The picture rating scale was apportioned such that 1 = Excellent, 2 = Good, 3 = Passable, 4 = Not Quite Passable, 5 = Poor, and 6 = Not Usable. The points marked with an X represent VHF observations, and those marked with an O represent UHF observations. Field strength is measured in dbu which means db above one microvolt per meter.

It will be noted in Fig. 2 that some of the points are marked with a star. These particular points were deleted from a revised figure (Fig. 3), because, in each of the measurement locations represented, there was a special anomolous situation that made the data unrepresentative. In addition, three points were added on Fig. 3 that did not appear on Fig. 2. The explanation of each of these deleted and added points is listed below.

1. In preparing Fig. 3, the following points (which appear in Fig. 2) were deleted. These are indicated by stars in Fig. 2.
   a) Channel 10, $Q_m = 6$; $E_m = 40.5$ dbu. Only one observation of picture quality was made. At that location, the householder's antenna was pointed approximately 180 degrees away from the station on Channel 19.
   b) Channel 19, $Q_m = 6$; $E_m = 59.5$ dbu. All receiving antennas were pointed approximately 180 degrees away from the station on Channel 19.
   c) Channel 17, $Q_m = 3.5$; $E_m = 41$ dbu. There were only four operable UHF receivers in this measurement location. The area is obviously not served by Channel 17. Median picture rating was abnormally high due to the presence of two or three excellent antenna installations and the resulting good pictures. $Q_m = 3.5$ does not properly represent the Channel 17 service in this area.

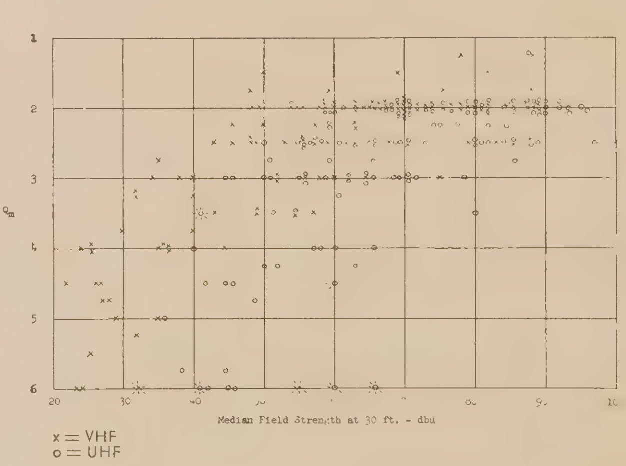

Fig. 2—All UHF and VHF original data.

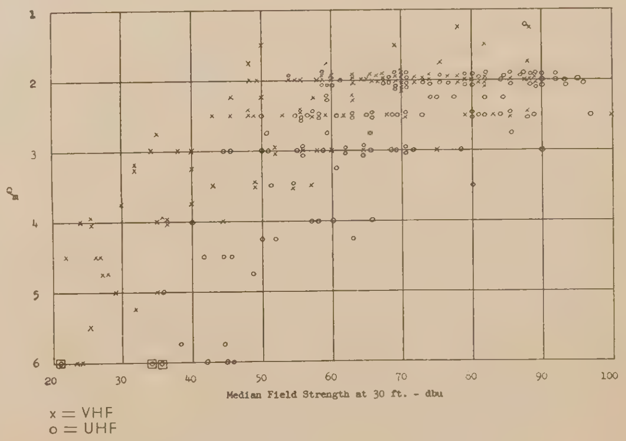

Fig. 3—All UHF and VHF valid data.

  d) Channel 12, $Q_m=6$; $E_m=55$dbu. Antennas were all pointed toward another station.
  e) Channel 24, $Q_m=4.5$; $E_m=59.5$ dbu. Antennas were all pointed toward another station.
  f) Channel 10, $Q_m=6$; $E_m=32.5$ dbu. Only one observation on this station, and antenna was pointed in the wrong direction.
  g) Channel 67, $Q_m=6$; $E_m=66$ dbu. Another closer station on VHF carried the same network and UHF receivers and antennas were no longer used.

2. In preparing Fig. 3, the following points (which do not appear in Fig. 2) were added. These are shown as circles in boxes in Fig. 3.
  a) Channel 17, $Q_m=6$ (added); $E_m=33.5$ dbu.
  b) Channel 28, $Q_m=6$ (added); $E_m=36.5$ dbu.
  c) Channel 67, $Q_m=6$ (added); $E_m=22$ dbu.

In each of these three measurement locations, there was no evidence of any service from the stations listed, and it was felt that a picture rating of 6 properly represented the facts.

For purposes of analysis and discussion it is interesting to split the data of Fig. 3 still further. Fig. 4 is a plot of the low channel 30-foot VHF data alone. Fig. 5 is a plot of the high channel 30-foot VHF data. Fig. 6 is a plot of low channel 30-foot UHF data, and Fig. 7 is a plot of the middle and high channel 30-foot UHF data. A low UHF channel will be defined as Channel 40 and below. Anything above Channel 40 will be considered a middle and high UHF channel. Fig. 8 is a plot of all of the 30-foot VHF data, and Fig. 9 is a plot of all the 30-foot UHF data.

It may be wondered by some readers how the figures could have half and quarter steps between the individual six points of the judging scale. The half steps arise because the median of an even number of observations is the average between the two middle observations. In addition, the quarter steps arise because each point has a picture rating determined by the average between the median engineer's opinion and the median householder's opinion.

One of the purposes of these tests was to examine the correlation between picture and field strength, with measurements being made at both a ten foot antenna height and a thirty foot antenna height. All of the data presented thus far were for field strengths at thirty feet. Fig. 10 presents all valid median data for an antenna height of ten feet. Fig. 11 is a plot of low channel ten-foot VHF data. Fig. 12 is a plot of high channel ten-foot VHF data. Fig. 13 is a plot of low channel ten-foot UHF data. Fig. 14 is a plot of medium and high channel ten-foot UHF data. Fig. 15 is a plot of all of the VHF ten-foot data, and Fig. 16 is a plot of all of the UHF ten-foot data. Only valid data are plotted in the ten-foot data figures. That is, anomalous points mentioned earlier have been removed.

The significance of these figures is discussed in the next section on data analysis.

ANALYSIS AND DISCUSSION OF DATA

The differences in performance of television receiving equipment (receivers and antenna installations) operating in the various allocated bands are rather apparent from Figs. 2 through 16. Figs. 3 and 10 illustrate the over-all difference between VHF and UHF. Further, it is possible to subdivide clearly the performance differences between low and high VHF, as well as between VHF and UHF. Comparison of Figs. 4 and 5, as well as 11 and 12, shows degradation of receiving performance from low VHF to high VHF. Comparison of Figs. 6 and 7 (and Figs. 13 and 14 to a lesser extent) shows deterioration from low UHF to middle and high UHF. Most important, Figs. 8 and 9, as well as Figs. 15 and 16, show the over-all degradation from VHF to UHF. It should be noted that, for any given field strength, UHF receiving installations suffer in comparison with VHF installations in at least three important respects—lower antenna conversion factor, higher transmission line loss, and inferior receiver performance, especially with respect to noise factor and sensitivity. These are discussed in detail in the report of Panel 2, and in the paper in this issue by W. O. Swinyard.[2]

Some comment on a comparison of 10- and 30-foot measurements is in order. At the VHF channels, comparison of low channel VHF data (Figs. 4 and 11) indicates that the scattering of points is comparable, but that the 10-foot signal is lower. Comparison of high channel VHF data (Figs. 5 and 12) leads to somewhat similar conclusions. Comparison of low channel UHF data (Figs. 6 and 13) is more difficult because of the absence of low signal data and the scattering of existing data. This is partly due to the fact that the UHF signal disappears much more rapidly with distance over the horizon. Further, standing wave field patterns tend to be more severe at the UHF channels. Comparison of medium and high UHF data (Figs. 7 and 14) suffers from similar problems. In all cases, however, the differences in receiving performance are clearly marked for either 10- or 30-foot field strengths.

It must be remembered that these differences in receiving performance (antennas, transmission lines, and receivers) are due to two fundamental causes. The first can be classified as "state of the art" difficulties. This includes transmission line losses and receiver noise figure. The second has to do with problems of fundamental physics. The most important of these is the lower antenna capture area of antennas of the same type as the frequency is increased.

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[2] W. O. Swinyard, "VHF and UHF television receiving equipment," this issue, p. 1066.

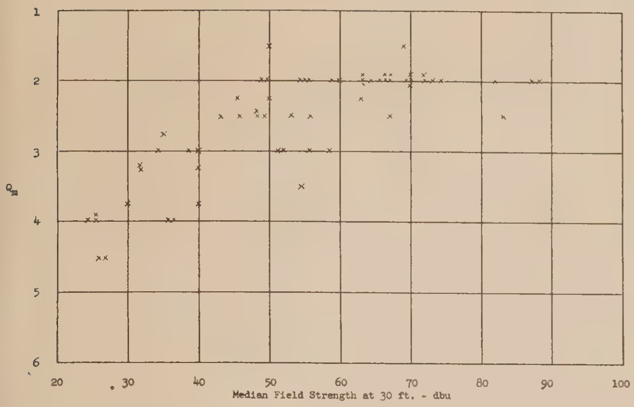

Fig. 4—Low VHF data—Channels 2–6.

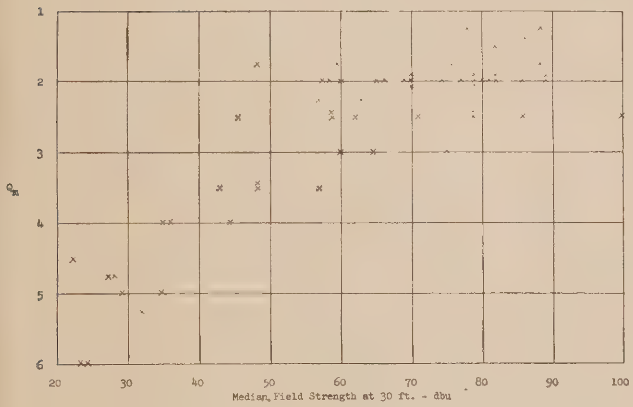

Fig. 5—High VHF data—Channels 7–13.

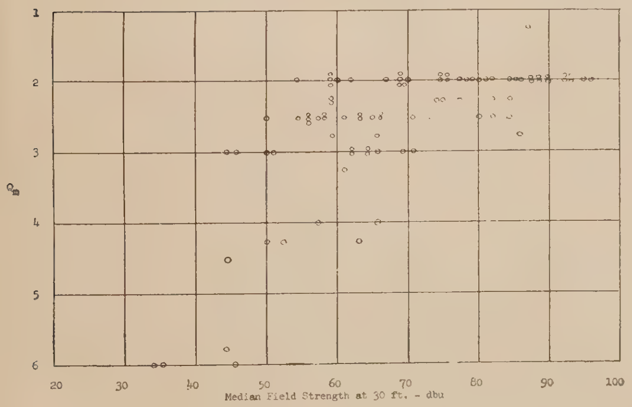

Fig. 6—Low UHF data—Channels 14–40.

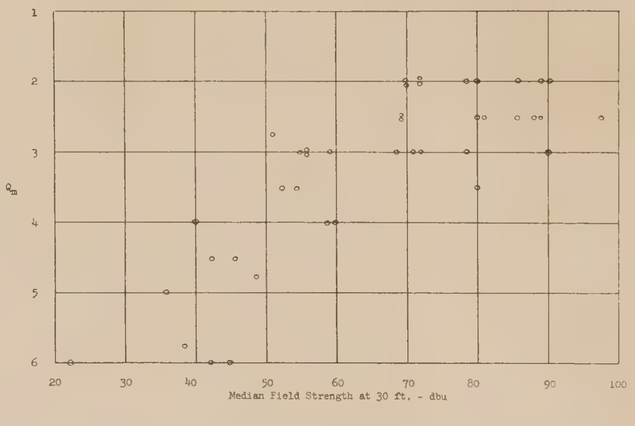

Fig. 7—Middle and high UHF data—Channels 41–83 (primarily middle UHF).

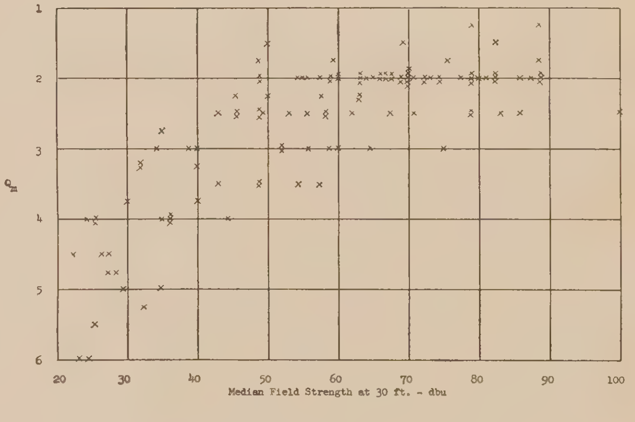

Fig. 8—All VHF data—Channels 2–13.

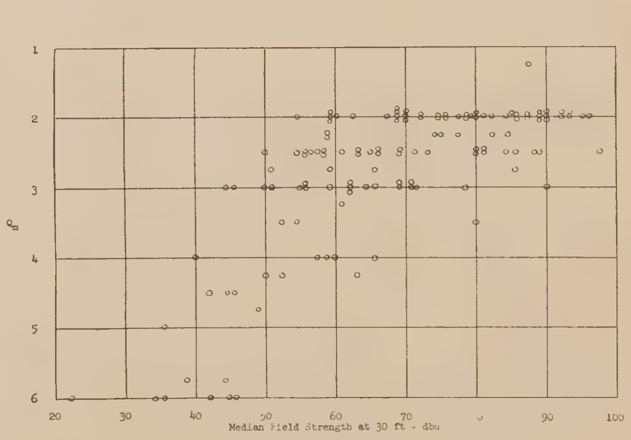

Fig. 9—All UHF data—Channels 14–83.

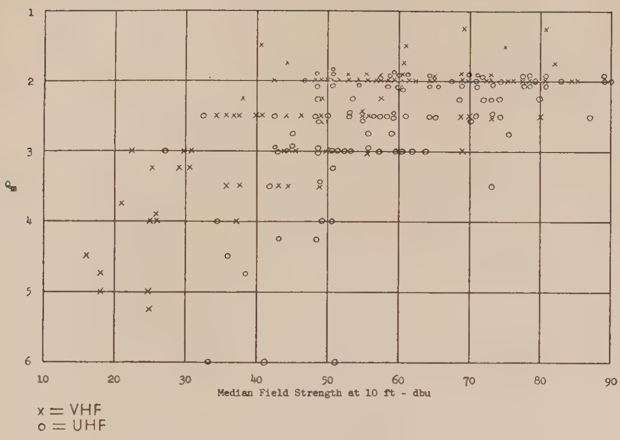

Fig. 10—All UHF and VHF valid data.

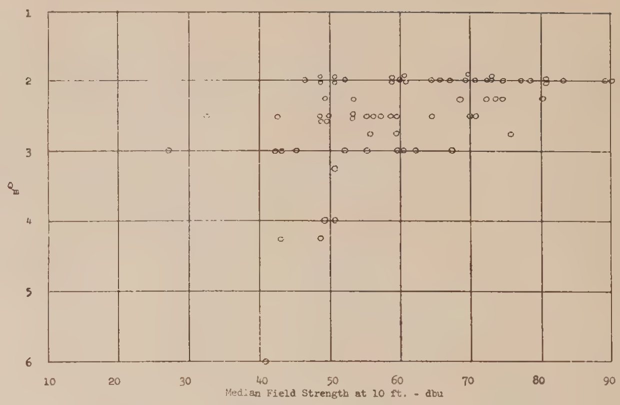

Fig. 13—Low UHF data—Channels 14–40.

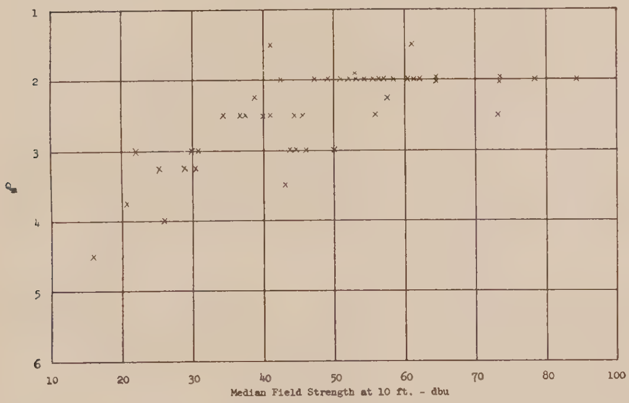

Fig. 11—Low VHF data—Channels 2–6.

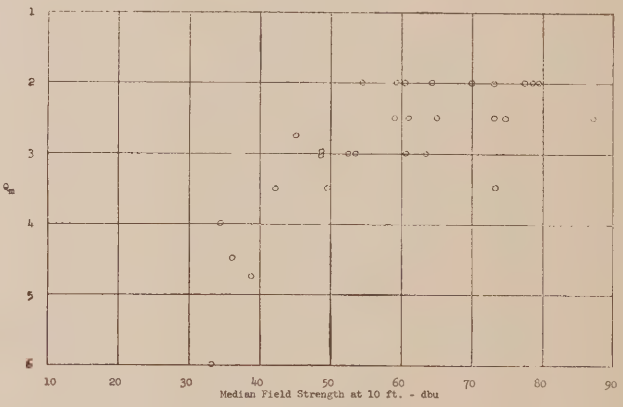

Fig. 14—Middle and high UHF data—Channels 41–83 (primarily middle UHF).

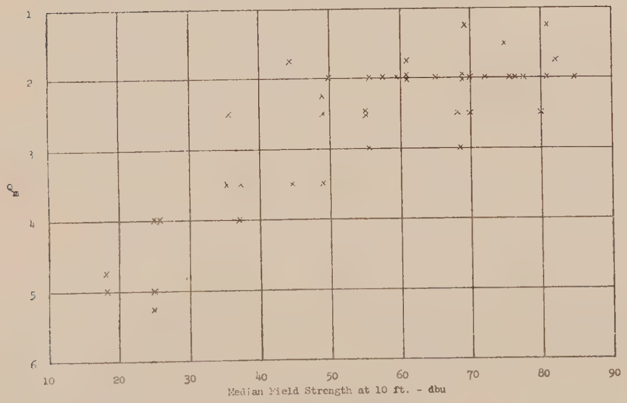

Fig. 12—High VHF data—Channels 7–13.

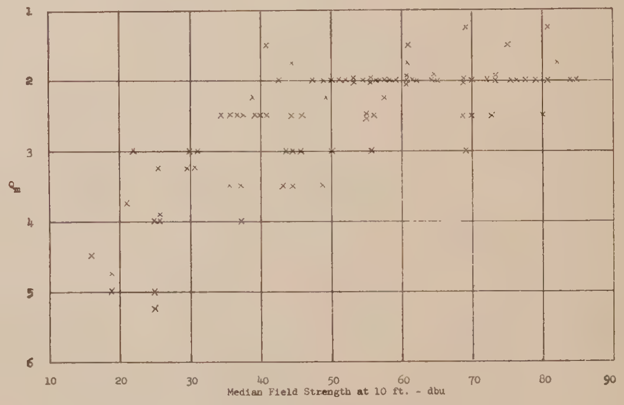

Fig. 15—All VHF data—Channels 2–13.

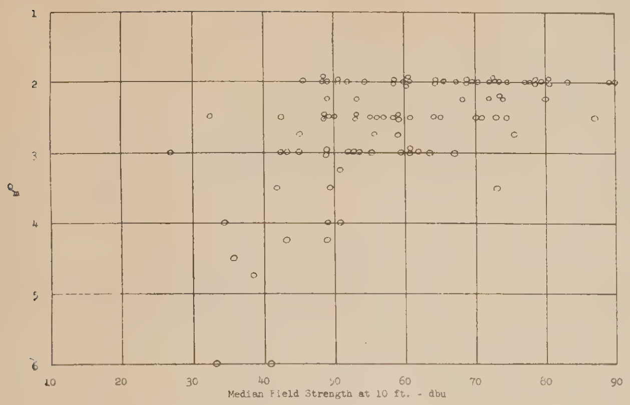

Fig. 16—All UHF data—Channels 14–83.

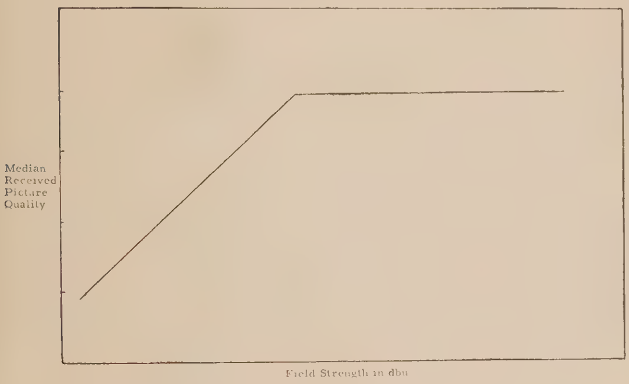

Fig. 17—Idealized picture quality—field strength characteristic.

The over-all nature of Figs. 2 through 16 seems to indicate a general performance characteristic that might be expected. This characteristic is idealized in Fig. 17.

First, in high signal areas, it would be expected that some variation in receiver performance would be encountered due to the variation of receiver and antenna degradation, variations of service quality, etc. The average receiver performance, however, would be relatively independent of field strength as indicated by the horizontal part of the sketch. It is important to note from Figs. 4 through 7, as well as from Figs. 11 through 14, that the variability in this high signal performance is apparently more extensive as the frequency is increased. A second type of performance characteristic to be expected is that, as the signal becomes weaker, the set performance becomes more and more dependent upon signal strength as indicated by the sloping part of the sketch. Presumably, the other variables are still present. One interesting situation was noted throughout the survey. That is, the general quality of receiver installation and state of repair of the average receiver improved as the distance from the transmitter increased, since a fringe receiver must be in better condition to give a usable picture than a receiver close to the transmitter. This "feed-back with distance" characteristic was sometimes so pronounced that average picture quality (particularly at VHF) improved as distance increased out to perhaps twenty or thirty miles. As the signal gets very weak, however, the received picture obviously degrades, and degradation unquestionably goes up with frequency.

Some other interesting points can be obtained from the interview sheets. These are summarized here. It is interesting to examine the UHF conversion figures on an over-all basis. These are given in Table I for a total of 396 homes which had UHF conversion.

TABLE I

Distance from Transmitter (Miles)	Total Homes Visited Having Television in a Mixed VHF-UHF Service Area	Total Television Sets Converted to UHF	Per Cent Conversion
0–10	61	51	84
11–20	160	122	76
21–30	155	108	70
31–40	168	98	58
41–50	32	13	41
51–60	25	4	16

It is interesting to note that of these 396 television sets, 41, or slightly over ten per cent, were inoperative on UHF while they were operative on VHF. No receivers are included in this tabulation which were inoperative on both UHF and VHF. Due to the technical nature of the UHF tuners, no sets were found which were operative on UHF but not on VHF. It should be pointed out that the Fresno, California, data are not included in Table I. This is because the transmitter antenna heights are such that UHF propagation is not representative of conditions in the remainder of the country. In Fresno, good UHF as well as VHF pictures were received at distances as high as 100 miles from the transmitters. This was essentially line-of-sight transmission, of course.

It was found that very few external converters are used for UHF. Further, these are used only in old UHF areas, and are rapidly being replaced with internal units as the old television sets are replaced. Most combination UHF-VHF installations use separate transmission lines, and the usual line for UHF is round twin lead, whereas flat twin lead is almost universally used for VHF.

The average time to the last service call over the country, as determined by this survey at least, is $6\frac{1}{2}$ months. This figure varied widely from area to area, of course. The quality of television service observed varied from area to area. In some communities, for example, almost every television receiver observed was in good operating condition. In others, almost all were in bad operating condition. All degrees in between the extremes were observed. The same general statement, although perhaps to a lesser degree, could be made of antenna installations. The reports from the survey teams indicate that the average television service level throughout the country needs considerable improvement. Generally, more deficiencies in receiver operation were noted due to such things as alignment, than to antenna and receiver installation. This is probably to be expected, since to remedy the former difficulty needs much higher skill on the part of a serviceman than to remedy the latter. Further, a large percentage of service shops are inadequately equipped with test equipment.

General Conclusions

Some general conclusions can be drawn based on the preceding material, and also on some general observations made during the survey.

With certain obvious exceptions, down to a field strength of 60–70 dbu on the average, the best and the worst pictures observed in a measurement location were both UHF pictures. (This statement holds, of course, only for areas served by both UHF and VHF.) These field strengths correspond generally to distance ranges roughly out to the optical line-of-sight. Thereafter, UHF field strength and picture quality deteriorate rapidly while good VHF service holds for considerably greater distances. The rapid deterioration of UHF over VHF is apparently an over-the-horizon propagation problem. In areas where UHF line-of-sight is 75 to 100 miles, UHF service holds up almost comparably with VHF to those distances. This fact was brought out quite forcibly in the Fresno, California, survey. The statement about the best and the worst pictures both being UHF pictures is not difficult to explain. In areas of *adequate* signal strength, UHF does not appear to be subject to ignition noise, airplane flutter, and so forth. Thus the "best" picture is explained. The "worst" picture is explained by the fact that for any given median signal strength in an area, the gamut of receiver performance at UHF is much wider than at VHF.

It was interesting to note that for the most part, the householder did a fairly competent job of operating the receiver. There were exceptions, of course, but in perhaps 75 per cent of the cases, the engineer would not have done much better.

It was definitely noted that, as the distance from the transmitter increased, the average quality of antenna installation improved, and the average service condition of the receiver improved. A much higher percentage of misaligned or otherwise improperly operating receivers was noted close to the transmitters than was noted at considerable distance away (20 miles and above).

Although there is considerable room for individual judgment, Figs. 4 through 7 would seem to indicate that for a *Passable* picture the following mean field strengths at thirty feet in a measurement location are required.

Low VHF	40–45 dbu,
High VHF	50–55 dbu,
Low UHF	55–60 dbu,
Middle and High UHF	62–67 dbu.

There were not enough data to separate middle and high UHF.

It is important to realize that this does not mean that these figures at a receiving antenna will give a passable picture. Rather, they mean that when these figures represent the mean field strength at thirty feet, the height of receiver antennas and quality of receiver performance and installations will be such that median picture quality in that measurement location will be passable. The reader may choose appropriate figures from the ten foot data by examining Figs. 11 through 14, if he desires.

For a *Good* or better picture, the following values of field strength appear to be adequate at thirty feet.

Low VHF	50 dbu and above,
High VHF	60 dbu and above,
Low UHF	65 dbu and above,
Middle and High UHF	72 dbu and above.

It should be noted that the preponderance of low signal VHF data was taken in the northern Minnesota area. This does not detract from the validity of the data as far as correlation between picture quality and field strength is concerned, but may restrict the generality of any conclusions that might be drawn about the receiving antenna height-gain function.

Relative Performance of Receiving Equipment as Reported by Television Servicemen*

HOLMES W. TAYLOR†

Summary—**Incorporate with the over-all study conducted by TASO, Panel 3 (Field Tests) in its study of reception problems conceived a six-page questionnaire which was circulated to that segment of the industry most closely associated with these problem areas—the television servicemen in communities across the nation. The questionnaire dealt with reception conditions, antennas, transmission lines, receivers and allied questions on both VHF and UHF covering both color and monochrome. The statistical compilation of answers received from the cooperating TV servicemen is included in this paper.**

In conjunction with the Television Allocation Study Organization, Panel 3 (Field Tests) brought Committee 3.4 (Analysis of Questionnaires) into being at its 10th Meeting in March, 1958.

This committee was charged with the responsibility of reducing the data obtained from the television servicemen's questionnaires to a form suitable for summarization and analysis. While the questionnaire is not reproduced in this paper, all of the pertinent questions head the various tabulations of the results. All original data, including that generated by the Committee, have been turned over to the FCC.

The Committee received 730 completed questionnaires. Since it was decided to transfer pertinent data from the questionnaires to punched cards, the questionnaires were sorted alphabetically by state and by cities within the state. In this way, the serial number of a questionnaire allowed ready reference to geographical information. The questionnaire data were reduced to numerical alphabetical codes which greatly simplified the summary work and reduced punched card volume.

It became apparent during the preparation of format sheets prior to actually preparing the cards that some of the data had been subject to local interpretations or appeared to be erroneous. After checking through a number of cases, it also became apparent that a certain amount of inconsistency would be averaged out as part of the normal statistical analysis. In addition, the Committee felt that, in the area of interpretation, it should not attempt to reinterpret data since this in itself would tend to disqualify them. However, certain basic ground rules were followed. Data with no meaningful significance (*i.e.*, a question either left blank or answered in such a way that it could not be resolved), were omitted from the summaries. Furthermore, those few areas which called for written comments covered such a wide field of answers that it was decided in the summary only to indicate whether or not the question had been answered.

Finally, in picking the maximum quantity size for various parameters, some answers beyond the capacity chosen were discovered. These were so few that they were included at the maximum number and it was felt that this would not disturb the relative relationship of the final results.

Before presenting the results of the analysis, there are several points which should be considered. The data presented reflect the results of the servicemen's experiences and consequently the receiver information is limited to those sets which have required professional servicing. Thus, in interpreting the results, one must keep in mind that there were undoubtedly a number of receivers which either required no servicing or were serviced by the owner. For example, in the table where it is indicated that the average number of calls per set per year is approximately three, the figure would be reduced if the number of unserviced sets within the average serviceman's area of endeavor were known. While this is a fairly obvious point, it is sometimes overlooked in reviewing data of this nature. In order to place the results of this survey back into the same perspective originally intended, the results are tabulated in the same order as the questions were presented in the questionnaire and divided into six sections:

A. General Information;
B. Receiving Antennas;
C. Receivers;
D. Multipath (Ghost) Problems;
E. Interference;
F. Color Reception.

The actual question from the survey questionnaire has been repeated, and heads each tabulation.

A. GENERAL INFORMATION

The first three questions in this section of the questionnaire were not summarized, since these questions were used to establish identification and area location of the reporting serviceman. This information for each questionnaire, along with its individual identification number, appears on the punch cards that were used.

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* Original manuscript received by the IRE, February 11, 1960.

† Res. Center, Burroughs Corp., Paoli, Pa.

The state and city address of the serviceman was used to establish in which FCC Zone (*i.e.*, I, II or III) he was located, and the following data were established from the information:

a) That questionnaires were returned from 46 of the 48 states (Delaware and Vermont abstaining).

b) That 44 per cent of the questionnaires came from Zone I.

c) That 44 per cent of the questionnaires came from Zone II.

d) That 12 per cent of the questionnaires came from Zone III.

4(a). Please estimate the number of calls per year you make on the following types of receivers:

	Survey Totals	Average Total per Questionnaire	Aggregate Response
VHF	2,975,031	4605	89 per cent
UHF Converter Sets	145,187	621	32
UHF Single-Channel Sets	1762	28	9
All-Channel Sets	392,869	1224	44
Strip-Tuner-Equipped Sets	336,342	998	46
Community-TV Sets	25,686	299	12
Centralized-Receiver-Systems Equipment	2382	21	16

4(b). Please estimate the number of service calls you make PER SET PER YEAR on the following types of receivers:

	Survey Totals	Average Total per Questionnaire	Aggregate Response
VHF	1911	3.11	84 per cent
UHF Converter Sets	856	3.93	30
UHF Single-Channel Sets	153	2.94	7
All-Channel Sets	1139	3.93	40
Strip-Tuner-Equipped Sets	948	3.27	40
Community-TV Systems Sets	242	2.99	11
Centralized-Receiver-Systems Equipment	290	3.15	13

5. For the area you service, please indicate the number of TV antennas you have installed:

	Survey Totals	Average Total Per Questionnaire	Aggregate Response
VHF Indoor Antennas	538,443	1213	61 per cent
UHF Indoor Antennas	78,010	441	24
VHF Rooftop Antennas	829,538	1440	79
UHF Rooftop Antennas	148,932	532	38

Based on the above data, dividing the total calls by the average number of calls per set for a given receiver, furnishes this tabulation of receiver sets serviced per year.

	Receiver Sets
VHF Receivers	957,000
UHF Converter Sets	37,100
UHF Single-Channel Sets	600
All-Channel Sets	100,000
Strip-Tuner-Equipped Sets	103,000
Community-TV Systems Sets	8580
Centralized-Receiver-Systems Equipment	755

Thus, excluding the centralized and community systems, the survey indicates a total of 1,197,000 serviced receivers with VHF capabilities and 240,700 serviced receivers with UHF capabilities. It is interesting to note that the percentage responding for VHF is approximately twice that for UHF. This trend, which shows that about half of the areas responding did not have UHF service, is found throughout the results.

6. Please indicate YES or NO to each of the following descriptions of your area:

	Survey Totals	Percentage Breakdown	Aggregate Response
a)			Over-all 97 per cent
Flat	266	38 per cent	
Hilly	220	31	
Flat and hilly	130	18	
Mountainous	16	2	
Flat and Mountainous	1	*	
Hilly and Mountainous	48	7	
Flat, Hilly and Mountainous	31	4	
b)			
Industrial	8	1	
Residential	92	13	
Industrial and Residential	99	14	
Rural	10	2	
Industrial and Rural	1	*	
Residential and Rural	94	13	
Industrial, Residential and Rural	405	57	

* Less than ½ of 1 per cent.

7. Please list in the columns below, the TV stations which provide service to your area. For comments on the usual grade of service, use E for Excellent, G for Good, F for Fair and P for Poor. (This refers to technical performance only, not programming.)

The original data were, of course, by station including call letters and channel numbers; however, in the summarization the channels have been grouped in the following way:

Low VHF	2–6
High VHF	7–13
Low UHF	14–40
Medium and High UHF	41–83.

The latter group was combined because of the low density of stations in this category. The tabulation below is of average distance in miles to the transmitting antenna and is organized by channel groups and grade of service. Response in this area was over 95 per cent.

Channel Group	Grade of Service			
	Excellent	Good	Fair	Poor
2–6	22 miles	37 miles	67 miles	76 miles
7–13	22	31	55	71
14–40	15	18	16	27
41–83	11	13	15	22

The data for average power used by the transmitting stations and the average relative height (vertical distance from top of transmitting tower to serviceman's area) were obtained from the "Television Digest Factbook" and a reference book on height above sea level for numerous locations in the United States. The averages for both power and transmitting height were based on averaging the total number of stations reported for each channel group. Since servicemen reported on the same stations in a number of cases, the average then is multiple station rather than single station average. The average transmitter height is perhaps greater than expected because of the occurrence of stations like WMTW, Poland Spring, Me., where the vertical distance from a serviceman in Portland to the top of the transmitting antenna was 6375 feet. These large heights tended, of course, to bring up the average. Finally, the over-all average, again on a multiple station basis, was 1210 feet.

Channel Group	Average Transmitting Station Power	Relative Antenna Transmitting Height
2–6	88 kw	1272 feet
7–13	240	1235
14–40	350	735
41–83	330	1179

A different analysis showed that there were 444 individual stations covered by the survey (includes six in Canada and one in Mexico). Due to overlap reporting, some of these stations were reported as many as 48 times. The nontranslator stations of this group are 427 and the total United States station density is 541. This survey then represents a 79 per cent coverage.

B. RECEIVING ANTENNAS

1(a). In your area, how would you rate the performance of a typical rooftop antenna?

1(b). In your area, how would you rate the performance of a typical indoor antenna?

Performance	Rooftop Antenna		Indoor Antenna	
	VHF	UHF	VHF	UHF
Excellent	51 per cent	35 per cent	7 per cent	2 per cent
Good	38	32	28	10
Fair	7	19	32	24
Poor	4	14	33	64
Aggregate Response	97	47	95	54

Note again that the response for VHF is approximately twice that for UHF.

2(a). In a strong-signal area, what are the minimum, average, and maximum outdoor receiving antenna heights you have observed? (Enter height estimates in feet above street level.)

2(b). In a weak-signal area, what are the minimum, average, and maximum outdoor receiving antenna heights you have observed?

Antenna Heights	Strong Signal Area	Weak Signal Area
Minimum	22 feet	29 feet
Average	32	40
Maximum	68	74

3. Selection of the location for an outdoor receiving antenna.

3(a). In weak-signal areas, do you explore the rooftop area for locations of maximum signal intensity?

	Yes	No	Aggregate Response
VHF	53 per cent	47 per cent	89 per cent
UHF	81	19	

3(b). Have you observed seasonal changes in the optimum location of outdoor antennas?

	Yes	No	Aggregate Response
VHF	43 per cent	57 per cent	92 per cent
UHF	63	37	

4. What proportion of receiver installations in your area receive less than optimum picture quality because the owner does not erect an outside antenna?

Proportions of Installations	Aggregate Response
30 Per Cent	95 Per Cent

5. What types of transmission lines are most often used?

Type of Area	Coax	Tubular	Flat	Aggregate Response
Strong Signal VHF	1 per cent	5 per cent	94 per cent	91 per cent
Strong Signal UHF	4	83	13	40
Weak Signal VHF	3	15	82	83
Weak Signal UHF	6	87	7	37

6. Is the transmission line length and/or installation ordinarily a factor in the choice between an indoor and an outdoor antenna?

	Yes	No	Aggregate Response
VHF	12 per cent	88 per cent	94 per cent
UHF	18	82	

7. Do you usually use separate VHF and UHF transmission lines to the receiver?

Yes	No	Aggregate Response
60 per cent	40 per cent	48 per cent

8. Please list your estimate of the minimum, average and maximum lengths of transmission line used for outdoor antennas in strong and weak signal areas at VHF and UHF:

	Strong	Weak	Aggregate Response	
			Strong	Weak
VHF Minimum	29 feet	36 feet	75 per cent	62 per cent
Average	50	57	81	70
Maximum	115	127	75	65
UHF Minimum	26	31	31	27
Average	44	50	34	29
Maximum	86	90	32	28

9. What type of outdoor antenna have you found most acceptable for MONOCHROME reception: dipoles, yagis, conicals, bow-ties, stacked combinations, corner reflectors, rhombics, others?

10. What type of outdoor antenna have you found most acceptable for COLOR reception: dipoles, yagis, conicals, bow-ties, stacked combinations, corner reflectors, rhombics, others?

The servicemen indicated in the questionnaire that the following types of outdoor antenna were used:

Bow-ties
Conicals
Dipoles
Corner reflectors
Helix
Inline, colinear, colateral
Parabolic
Rhombics
Folded or double V
Traveling-Wave
Yagis

For purposes of the analysis, the antenna types used in the table were reduced to five. These five represented a total usage of 80 to 95 per cent, while the use of the others was comparatively small.

Antenna Types

Reception Type	Area Type	Corner Reflectors	Conicals	Dipoles	Yagis	Bow-ties	Aggregate Response
Monochrome	Weak VHF	—	25 per cent	10 per cent	60 per cent	—	76 per cent
	Weak UHF	35 per cent	—	—	28	26 per cent	35
	Strong VHF	—	40	30	24	—	80
	Strong UHF	28	—	—	13	43	36
Color	Weak VHF	—	24	16	53	—	43
	Weak UHF	33	—	—	23	26	11
	Strong VHF	—	36	28	29	—	51
	Strong UHF	33	—	—	13	36	13

Note that here again the UHF responses are about 50 per cent of the VHF and that the area having color service was about 50 per cent of the UHF and VHF respectively.

C. RECEIVERS

1. What proportion of receiver installations are unsatisfactory?

	Percentage Unsatisfactory	Aggregate Response
VHF	15 per cent	95 per cent
UHF	11	83

In the following list, check reasons for this that have occurred in your experience. Opposite any troubles that are especially frequent, put several check marks.

The number of check marks have been analyzed for each of the performance problems within the specific receiver type only (*i.e.*, no correlation was attempted between receivers). The percentage response to this question, as a whole, was 84 per cent and was based on the fact that a man indicated at least one check mark for a particular trouble under at least one receiver type (this was the only method which determined that a man actually read and considered the question). There were a few cases where there were no check marks, but the part of the question allowing for other reasons had some notation. Those cases were considered valid. Although some of the blank remaining forms may have indicated no troubles, it is hard to bebelieve that a serviceman could have any experience to report on without having to service a receiver.

Performance Difficulty	VHF Receivers	UHF Converters	UHF Strip-Tuner Equipped Receivers	UHF Single-Channel Receivers	All Channel Receivers
Oscillator Drift	10 per cent	19 per cent	23 per cent	22 per cent	18 per cent
Difficulty in Tuning, Tuning too Critical	11	18	16	18	18
Short Tube Life	30	25	19	30	32
Dissatisfaction with External Boxes	3	12	3	3	2
Failure of Beating Oscillator to Cover the Range	3	3	4	4	3
Inadequate Dial Channel Identification Markings	7	6	6	5	8
High Noise Level	20	7	15	8	8
Beat Notes	11	6	9	6	6
Self Oscillation	5	4	5	5	5
Other Reasons	Of the 84 per cent responding to the question as a whole, 33 per cent of this group indicated scattered reasons other than those specified.				

2. If you do business in a mixed VHF-UHF area, is it your experience that new receivers purchased are almost always, usually, or seldom, of the all-channel (UHF and VHF) type?

Purchase Frequency	Percentage Breakdown	Aggregate Response
Always	43 per cent	Over-all 42 per cent
Usually	28	
Seldom	29	

3. Has it been your experience that owners of combination VHF-UHF receivers know how to tune in either MONOCHROME VHF or UHF stations equally well?

Yes	No	Aggregate Response
55 per cent	45 per cent	46 per cent

4. Has it been your experience that owners of combination VHF-UHF receivers know how to tune in either COLOR VHF or UHF stations equally well?

Yes	No	Aggregate Response
55 per cent	65 per cent	30 per cent

D. Multipath (Ghost) Problems

1. What proportion of the total number of sets in your area suffer from ghosts?

	Percentage of Ghosts	Aggregate Response
VHF	12 per cent	83 per cent
UHF	19	23

2. Are ghosts more objectionable on VHF or UHF?

VHF	UHF	VHF and UHF	Aggregate Response
69 per cent	18 per cent	13 per cent	44 per cent

E. Interference

1(a). Listed below are some sources of interference. In the table, check the sources of interference which you have found to exist in your service area at UHF and VHF.

1(b). Please note in the table below the sources of interference you have found to be troublesome in the areas indicated.

The percentage response to this question as a whole was 98 per cent. In analyzing the interference data, the table has been organized such that percentages within the group responding for a particular interference are listed for VHF, UHF, or a combination of both. In addition, the percentage distribution which indicated the most troublesome areas is also shown within the framework of the response for a given type of interference. Since the area group, namely, business-industrial, residential, and rural, can receive either individual or composite checks, there results seven possibilities ranging from each one individually to all three combined. For analysis purposes we have selected the four most prevalent combinations which are business-industrial (B); residential (R); business-industrial and residential (BR); and business-industrial, residential, and rural (BRR). On this basis (4 out of 7), the percentages, when added across, will not necessarily total 100 per cent. Under the aggregate response column, the figure associated with VHF indicates the actual response to the area portion of the question for a given interference as a part of the total (*i.e.*, 98 per cent) response. The statement is similar for UHF. The third response figure represents that portion of the total response which indicated a check mark at UHF, VHF or both for a given interference.

	Band		B	R	BR	BRR	Aggregate Response
Motor Vehicle Ignition Systems	VHF	92 per cent	28 per cent	14 per cent	33 per cent	16 per cent	68 per cent
	UHF	1	36	10	26	18	6
	Both	7	—	—	—	—	86
Diathermy Machines	VHF	95	59	19	20	2	30
	UHF	*	54	8	38	0	2
	Both	5	—	—	—	—	50
Power Distribution Systems	VHF	89	31	9	14	21	35
	UHF	1	20	0	25	25	3
	Both	10	—	—	—	—	45
Neon Signs	VHF	94	86	4	9	1	40
	UHF	1	84	11	0	5	3
	Both	5	—	—	—	—	58
TV Receiver Radiation	VHF	81	9	60	18	4	20
	UHF	7	21	33	33	8	3
	Both	12	—	—	—	—	44
Standard AM Receiver Radiation	VHF	85	0	86	7	7	2
	UHF	7	0	0	0	—	*
	Both	8	—	—	—	—	9
FM Receiver Radiation	VHF	87	7	56	11	11	8
	UHF	7	50	25	0	0	1
	Both	6	—	—	—	—	21
Electrical Household Devices	VHF	88	4	47	9	9	44
	UHF	2	4	27	4	19	4
	Both	10	—	—	—	—	70
AM-FM Broadcast Station Radiation	VHF	86	10	45	21	11	16
	UHF	6	0	40	40	10	1
	Both	8	—	—	—	—	29
Shortwave Station Radiation	VHF	91	15	54	10	7	12
	UHF	3	7	57	7	14	2
	Both	6	—	—	—	—	29
Amateur Radio Stations	VHF	92	3	68	4	5	38
	UHF	2	0	58	17	21	3
	Both	6	—	—	—	—	63
Police Radio	VHF	78	26	36	17	8	19
	UHF	10	10	37	23	13	4
	Both	12	—	—	—	—	38
Special Service Communication Systems	VHF	73	33	28	17	9	12
	UHF	11	27	20	40	13	2
	Both	16	—	—	—	—	26

* Less than ½ of 1 per cent.
Note: 14 per cent of those responding specified other types of interference.

2. Do you find adjacent channel interference on VHF or UHF?

	Yes	No	Aggregate Response
VHF	55 per cent	45 per cent	Over-all 87 per cent
UHF	7	93	

3. Do you find co-channel interference on VHF or UHF?

	Yes	No	Aggregate Response
VHF	58 per cent	42 per cent	Over-all 86 per cent
UHF	4	96	

Note, however, that no duty factor was associated with these questions [E(2), E(3)]. Thus, effects could be of short irregular duration or only at special times of day or season.

F. COLOR RECEPTION

1. Does color TV seem to work better at VHF, at UHF, or does it work equally well at both bands?

Better at VHF	Better at UHF	Equally Well	Aggregate Response
61 per cent	18 per cent	21 per cent	25 per cent

2. If there are any differences between color reception at VHF and UHF, can you give any reason for these differences?

Of the group responding to F(1), 44 per cent provided written remarks in conjunction with F(2).

General Comments

In analyzing the original and final data which were obtained as part of the TASO survey, there are a number of highlights which are worth mentioning.

A close study of the servicemen's questionnaire indicated that those men who took the time to answer the questionnaire were quite thorough. We received very few questionnaires incompletely filled out. There were, of course, a number of unanswered questions for those areas that had neither UHF nor color service, and this is the reason for the reduced response in those areas. In cross-checking the total results of various sections of the questionnaire, those which dealt basically with the same problem areas showed a very close correlation. Therefore, we believe this indicates that the serviceman did not just make haphazard guesses but was particularly reliable in the way he went about answering the questions.

It is important to remember several things; one, that the sample size, which was 730, represents a small percentage of the total television servicemen throughout the country. In addition, it represents their knowledge as it pertains to receivers that have required attention. No attempt was made to try to derive a figure representing the number of receivers that might be considered as within the area of operation of the serviceman reporting. The accumulated data, of course, are in line with the purpose of the survey which was aimed at finding out just what the problems were, and we feel that many of the sets that have not been repaired by the serviceman have, statistically, somewhat the same problems with respect to ghosts and interferences.

Then, as previously mentioned, there is no doubt that a number of sets were repaired by the owner. The coverage resulting from the survey is particularly gratifying. For example, of the three FCC Zones, the two larger each returned 44 per cent of the data, while the third and smaller zone returned 12 per cent of the total. Also, 46 out of 48 states were represented. In addition, it is a significant fact that out of the 541 individually operating television transmitting stations in this country, this survey covered 427, which represented 79 per cent. These facts greatly increase the importance of the data obtained because they indicate that although the sample may have been small, the coverage was large and quite complete.

It was not the prerogative of this committee to draw definite conclusions from the data presented; however, this report is annotated in several places to point out results that seem to be of particular interest, and in addition, many conclusions are self-evident based on the data themselves.

Acknowledgment

Much of the credit for the effectiveness of this work must be given to the members of Panel 3 who consulted and aided our Committee. The efforts of H. E. Rhea, Director of Engineering, Radio & TV Division, Triangle Publications, Inc.; G. B. Frankenfield, Supervisor Programming Section, Research Center, Burroughs Corporation; and E. H. Boden, Senior Engineer, Sylvania Electric Products, Inc., who served as members of this committee, made it possible to accomplish this work. Special credit is due Sylvania Electric Products, Inc., who completed all final tabulations for the committee.

VHF and UHF Television Receiving Equipment*

WILLIAM O. SWINYARD†, FELLOW, IRE

Summary—**This paper covers a study of various types of VHF and UHF television receiving equipment made by TASO Panel 2 and reported October 3, 1958. Information and performance data are given for antennas, transmission lines and television receivers. RF amplifier and oscillator electron devices (tubes and semiconductors) used in television tuners for both VHF and UHF are discussed and tables showing relative performance data for devices of various types are included.**

In addition to this study of home television receiving equipment, TASO Panel 2 made studies of 1) community television antenna and distribution systems, and 2) the effects of transmitter sound power reduction on television receiver performance. Results of these studies are also included.

In general, data collected by Panel 2 show that performance of VHF equipment is markedly superior to that of UHF equipment and that a reduction in sound power of television transmitters is harmful to television reception, particularly in fringe areas.

INTRODUCTION

TASO Panel 2 was charged with the task of securing reliable information, on both theoretical and practical bases, for the purpose of appraising the present performance of television receiving equipment (monochrome and color) for both VHF and UHF broadcasting on all presently allocated channels. The presently allocated VHF channels are 2–6 in the frequency band of 54–88 mc and 7–13 in the 174–216-mc band. The UHF band is continuous in coverage from 470–890 mc and includes 70 channels numbered 14–84. All channels, both VHF and UHF, are 6 mc wide.

Performance data on antennas, transmission lines and television receivers were obtained by Committee 2.4 directly from the manufacturers of the equipment. Forms for use in recording the data were worked out and sent to the manufacturers along with specific instructions regarding the measurement methods to be used. In the case of antennas, the measurement standard, where applicable, was Electronic Industries Association (EIA) Standard REC-141, "VHF Antenna Performance Presentation and Measurement," which was used for both VHF and UHF antennas. In the case of television receivers, since no up-to-date measurement standard was available, a comprehensive manual, "Measurement Methods," was compiled. This was based on the experience of those skilled in the field and included methods of measurement which were considered to be the best available.

The antenna and transmission line questionnaires were mailed to 52 manufacturers of antennas, 11 manufacturers of transmission lines, and 37 manufacturers of television receivers. After follow-up letters, seven questionnaires were returned with data, five of which provided fairly complete data on the material manufactured by the sources. The data received in reply to the questionnaires, along with valuable data from three other sources, were analyzed and the results appear in this paper.

The television receiver questionnaires, manual of "Measurement Methods" and instructions were sent by Committee 2.1 to all known manufacturers of television receivers and tuners. Replies and data were received from 16 receiver manufacturers, and three tuner manufacturers, covering 78 different receiver chassis and nine tuners. These data were analyzed, the performance characteristics averaged, and the results are presented herein.

All electron devices (tubes and semiconductors) now being used by tuner and set manufacturers were reviewed by Committee 2.7 and tables of data considered important to the performance of these devices as they are used in television tuners were derived and are presented in this paper. In addition, tubes designed for VHF and UHF applications, but whose commercial usage has not yet developed, were added to the lists in order to give an up-to-date picture of their performance capabilities.

Information on community antennas and distribution systems was obtained directly from the operators by Committee 2.5. Answers to questionnaires were received from operators of 125 community television systems.

The effects of transmitter sound power reduction were studied by Committee 2.6. Tests were made in the laboratories of committee members using representative receivers under conditions closely simulating those actually encountered in the field.

ANTENNAS AND TRANSMISSION LINES

Data on antennas and transmission lines received from seven manufacturers, supplemented by data received from The Association of Maximum Service Telecasters (AMST) and the RCA Service Company were analyzed.

The questionnaire data which were sent in by seven of the 52 manufacturers to whom the questionnaires were sent contain data on 26 VHF and four UHF antennas. Although only seven of the 52 manufacturers sent in data, it is believed that the data are representative since they came from the larger manufacturers.

The AMST data cover 13 all-channel VHF antennas and two special Yagi antennas. The RCA Service Company data cover nine all-channel VHF antennas, one high VHF channel antenna and one Yagi single-channel antenna; they also cover six all-channel UHF

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* Original manuscript received by the IRE, January 11, 1960.

† Hazeltine Research, Inc., Chicago, Ill.

antennas and two Yagi antennas designed for specific channels.

Data on transmission lines were received from three of the 11 companies to whom the questionnaire was sent. These companies, however, are the larger ones in the field and for this reason it is felt that significant conclusions may be drawn from the data.

Table I summarizes the more important characteristics of antennas and transmission lines. It can be seen that the gain of UHF antennas is somewhat higher than the gain of VHF antennas when it is measured with respect to a half-wave folded dipole antenna. However, as the frequency increases the reference dipole becomes shorter; hence, it is not as effective in picking up signal at UHF as it is at VHF frequencies. The effectiveness is inversely proportional to frequency, and this fact must be taken into consideration when comparing the gain of VHF and UHF antennas. The dipole constant[1] λ/π shown in Table II takes cognizance of this fact. The dipole constant, in db[1] (also called the antenna lambda factor) added algebraically to the antenna gain, in db, with respect to a half-wave dipole gives the relationship between the incident field intensity and voltage at the receiver input terminals, neglecting transmission line loss.

Theoretically it is possible for the antenna to deliver a constant voltage to the load on all television channels if the field strength is the same for all channels. This requires a constant capture area for all channels.[2] The capture area (sometimes called the effective area or aperture) is $G_1\lambda^2/4\pi$, where G_1 is the power gain as a transmitting antenna relative to an isotropic radiator.[3] For a half-wave dipole G_1 is 1.64 and the capture area is $0.130\lambda^2$. The capture area for a dipole resonant at the center frequency of channel 2 is 38.5 square feet. To maintain this area for all channels requires the use of some sort of high-gain directional antenna at the higher frequencies and particularly at UHF where, for example, a dipole, or dipoles, mounted at the focal point of a parabolic reflector might be used. However, such an antenna has not come into general use in television reception.

It can be seen from Table II that for practicable antennas, and assuming uniform field strength at all frequencies, the signal delivered by the antenna to the input of the transmission line is −5.9 db and −15.6 db at high VHF and UHF, respectively, with reference to low VHF. This loss is further increased by losses in the transmission line. The net result is shown in the last two columns of data in Table II. These data show that in an

TABLE I

SUMMARY OF CHARACTERISTICS OF ANTENNAS AND TRANSMISSION LINES

TV Band	Gain, db[1]			Front/Back Signal Ratio, db			Horizontal Beamwidth (6 db), Degrees			Transmission Line Loss (100 feet), db					
										New, Dry			5 Years Old, Wet		
	Min	Av	Max	Min	Av	Max	Min	Av	Max	Min	Av	Max	Min	Av	Max
Low VHF	−7.0	3.7	11	0	11.6	30.4	55	109	360	0.7	0.9	1.2	2.1	5.1	8.0
High VHF	−2.5	6.8	12.8	2.2	10.6	26	24	59	210	1.5	1.7	1.9	4.2	9.7	14
UHF	−0.2	7.7	13.5	2.7	15.1	25	30	65	120	2.8	3.6	4.5	7.5	20.0	31

[1] Referred to a tuned, folded dipole.

TABLE II

RELATIONSHIP BETWEEN INCIDENT FIELD STRENGTH AND VOLTAGE AT RECEIVER INPUT TERMINALS

TV Band	Average Antenna Gain	Dipole Constant, K_d (Lambda Factor)	Ratio of Voltage at Transmission Line Input to Incident Field Strength	Average Transmission Line Loss (30 feet)		Ratio of Voltage at Receiver Terminals to Incident Field Strength	
				New, Dry	5 Years Old, Wet	New Dry Line	5-Year Old Wet Line
Low VHF	3.7 db	2.9 db	6.6 db	0.3 db	1.5 db	6.3 db	5.1 db
High VHF	6.8	− 6.1	0.7	0.5	2.9	0.2	− 2.2
UHF	7.7	−16.7	−9.0	1.1	6.0	−10.1	−15.0

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[1] The dipole constant is the ratio of the voltage at the transmission line terminals of the dipole antenna to the uniform field strength of the field in which the dipole is located. Its dimensions are therefore those of voltage/field strength or volts/(volts/meter) = meters. By definition, a db is a dimensionless quantity, being proportional to the logarithm of the ratio of two quantities having the same dimensions; therefore, it is not rigorously correct to express the dipole constant as so many db. Since all other quantities entering into this discussion are correctly expressed in db, it is convenient also to express the dipole constant on a logarithmic scale so that the gains (or losses) of all elements may be added to give the over-all gain (or loss) of the system as a whole. The dipole constant has therefore been expressed as

$$K_d \text{ (in db)} = 20 \log_{10} \frac{\text{voltage (in volts)}}{\text{field strength (in volts per meter)}}$$

with the knowledge that the expression is convenient rather than rigorously correct, and that the numerical result can be used only when the voltage and the field strength are expressed in units such that their ratio has the dimension of meters.

[2] G. H. Brown, J. Epstein, and D. W. Peterson, "Comparative propagation measurements: television transmitters at 67.25, 288, 510 and 910 megacycles," *RCA Rev.*, vol. 9, pp. 177–201; June, 1948.

[3] F. E. Terman, "Radio Engineering," McGraw-Hill Book Co., Inc., New York, N. Y., Third ed., p. 729; 1947.

average installation the signal delivered by the antenna to the receiver input terminals greatly favors the VHF receiver, and especially the low-frequency channels. The signal delivered to the receiver input terminals is −6.1 db and −16.4 db for the high VHF and UHF bands, respectively, with reference to the low VHF band, assuming equal field strength in all cases and new, dry transmission line. For old, wet transmission line the corresponding figures are −7.3 db and −20.1 db.

Although UHF antennas have been shown to deliver far less voltage to the receiver antenna terminals than VHF antennas, for a given field strength, there is some advantage in their generally smaller physical size.

RECEIVERS

Information concerning the more important circuit and performance characteristics of UHF and VHF receivers, including their susceptibility to various types of interfering signals, was supplied by 16 receiver manufacturers and three tuner manufacturers, covering 78 different receiver chassis and nine tuners. This represents a sufficiently large sampling of the industry to justify some rather general conclusions concerning the important circuit features and performance characteristics of present-day UHF and VHF receivers.

Consideration will be given first to the circuit features of UHF and VHF receivers. Most receivers employ a single transmission line input and are designed to receive VHF signals only. A few UHF/VHF receivers employ a single transmission line input with an internal crossover network. Most combination UHF/VHF receivers have dual inputs.

All VHF receivers reported have provision for reception of 12 channels which are selected by means of a switch having a detent mechanism. Provision is made for "fine-tuning" the selected channel for the best compromise of picture and sound. Most UHF receivers employ continuous tuning from channels 14 through 83, although a few divide the band into segments which can be selected by means of a switch and provide sufficient "fine-tuning" range to tune through each segment, thus covering the entire UHF band in discrete steps.

All VHF receivers employ an RF amplifier stage. Vacuum tubes are employed in the tuner and three tuned RF circuits are used in most cases. On the other hand, UHF receivers do not employ an RF amplifier stage. This matter will be discussed later. All UHF receivers have vacuum tube oscillators and crystal diode mixers, and most of them employ two RF tuned circuits.

All receivers reported, both VHF and UHF/VHF, employ the EIA standard video carrier IF of 45.75 mc. In combination UHF/VHF receivers the VHF tuner circuits are usually employed as IF amplifiers for UHF reception, thereby partially compensating for the losses in the UHF tuner.

Existing VHF television receivers can be adapted to receive UHF signals by means of a converter which, in conjunction with the receiver, operates on a double superheterodyne principle and uses one of the VHF channels as the converter intermediate frequency. No data on UHF converters were reported.

An important characteristic of a UHF converter is its ability to amplify weak signals to a usable level with a good signal-to-noise ratio. Most UHF converters employ a circuit consisting of a tuned preselector, an oscillator, a crystal diode mixer, an IF amplifier, and a power supply. The over-all noise factor of such a converter in combination with a VHF receiver is determined mainly by the following three characteristics:[4]

1) the losses in the preselector and crystal mixer circuits,
2) the noise factor of the converter IF amplifier, and
3) the noise factor of the VHF receiver.

The combined noise factor of the VHF receiver and converter IF amplifier is found usually to be only slightly higher than the noise factor of the converter IF amplifier alone, which may be assumed to be 6 or 7 db. This, combined with an assumed loss of about 10 db in the preselector and mixer circuits together, gives an over-all noise factor of about 16 to 17 db.

Other important converter characteristics are good oscillator stability, adequate selectivity, sufficient bandwidth and low oscillator radiation. A well-designed present-day converter can satisfy all of these requirements.

Converters may reasonably be considered as interim devices. Better results can be secured by using UHF receivers or combination UHF/VHF receivers.

The more important receiver performance characteristics are summarized in Table III. This shows the poorest, average and best results for each of the characteristics listed. It can be seen that the UHF receiver suffers in comparison with the VHF receiver in four major respects: 1) noise factor, 2) image ratio, 3) tuner bandwidth, and 4) oscillator stability. Average VHF noise factors are 6.5–8.5 db and average UHF noise factors are 12.8–13.8 db, a difference of about 6 db in favor of VHF. The image ratio performance is much poorer in UHF receivers. This is due to the practice of using a common IF for UHF and VHF receivers. This IF is as high as it can be for VHF but is too low for UHF; however, it seems to be a good compromise and no change is recommended. The RF bandwidth is much more favorable for VHF than for UHF, leading to fewer interference problems in VHF receivers. Oscillator drift is significantly less in VHF receivers. While the average drift in present UHF receivers is tolerable for monochrome reception, it is doubtful if it is sufficiently low for satisfactory color reception without retuning. Most receivers with remote tuning devices are also critically

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[4] W. Y. Pan, "Some design considerations of ultra-high-frequency converters," *RCA Rev.*, vol. 11, pp. 377–398; September, 1950.

TABLE III

Receiver Performance Characteristics

Channel	2–6			7–13			14–40			41–65			66–83		
Characteristic[1]	P	A	B	P	A	B	P	A	B	P	A	B	P	A	B
Noise Factor, db	9.7	6.5	4.6	12.2	8.5	6.5	16.7	12.8	10.5	18.2	13.2	10.0	19.0	13.8	9.5
Sensitivity, uv	150	40	4	270	57	6	360	79	10	280	76	8.5	300	81	11
Image Ratio, db	41	73+	80.5	45	68+	80	14	32	46	10	29	44	6	26	46
IF Interference Ratio, db	36	57+	76	53.5	68+	91	43	64+	88	43	65+	82	43	66+	86
Tuner Bandwidth[2] 3 db down, mc	10.5	7.5	4.0	14.0	9.4	3.5	37.0	17.5	8.0	34.0	18.5	9.0	60.0	25.4	10.0
Tuner Bandwidth[2] 20 db down, mc	22.5	14.8	6.0	37.0	23	8.0	125	48	15	178	59	16	247	74	18
Five-Minute Warmup Drift, mc	0.52	0.09	0.015	0.65	0.14	0.017	0.458	0.17	0.09	0.50	0.22	0.06	0.70	0.28	0.03
One-Hour Warmup Drift, mc	0.45	0.21	0.03	0.40	0.23	0.035	1.25	0.45	0.12	2.5	0.61	0.14	1.142	0.63	0.16
Input VSWR	6.0	2.7	1.0	6.0	2.4	1.0	5.0	2.4	1.0	5.0	2.4	1.0	5.0	2.5	1.0
Adj. Lwr. Snd.[3] Car. Atten., db	14	40	60	20	38	60	16	39	58	16	41	58	16	41	60
Adj. Upr. Pic.[4] Car. Atten., db	26	40	56	24	39	52	20	40	77	24	42	80	20	41	<80

[1] P, A, and B stand for poorest, average and best, respectively.

[2] In general, the broadest bandwidth is considered poorest and the narrowest is considered best. A lower number is generally more favorable down to about 6 mc.

[3] Channels used: 3–6; 8–13; 15–40; 41–65; 66–83.

[4] Channels used: 2–5; 7–12; 14–40; 41–65; 66–82.

dependent on oscillator stability. While VHF receivers are being sold in increasingly large numbers with remote tuning devices, at present such devices are not in widespread use in UHF receivers.

With respect to other performance characteristics for which data were obtained, the difference between UHF and VHF receivers is not significant.

Of the four points mentioned, wherein the performance of UHF receivers suffers by comparison to that of VHF receivers, the most important is the noise factor. The lack of a suitable low-cost RF amplifier tube for use in UHF tuners accounts for the relatively high UHF noise factors.

Not immediately apparent in the data is the fact that UHF receivers fall short with respect to amplification. It has been pointed out previously that this shortcoming in amplification in UHF tuners is at least partially compensated in combination UHF/VHF receivers by using the VHF tuner circuits to provide additional IF amplification. However, in receivers built for UHF reception only, provision would have to be made in the IF amplifier for this additional gain. This probably would require one, or possibly two, extra IF amplifier stages as compared with a VHF receiver. If an RF amplifier stage were used for improvement in noise factors, one additional IF amplifier stage would probably suffice because of the amplification supplied by the RF stage. The provision for additional IF gain for UHF reception in UHF/VHF receivers results in UHF sensitivity, which, while it is slightly poorer than that of VHF receivers, appears to be adequate considering the noise factors.

TABLE IV

Reduction in Receiver Input Terminal Voltage and in Signal-to-Noise Ratios for High VHF and UHF Bands Relative to Low VHF Band, for Equal Field Strengths[1]

TV Band	Reduction in Receiver Input Terminal Voltage[2]		Reduction in Signal-to-Noise Ratio[3]	
	Transmission Line New, Dry	Transmission Line 5 Years Old, Wet	Transmission Line New, Dry	Transmission Line 5 Years Old, Wet
High VHF	6.1 db	7.3 db	8.1 db	9.3 db
UHF	16.4	20.1	23.2	26.9

[1] Based on average noise factors as follows: Low VHF, 6.5 db; High VHF, 8.5 db; UHF, 13.3 db.

[2] Figures derived from last two columns in Table II.

[3] These figures were obtained by adding to the figures in columns 1 and 2 the average noise factors relative to low VHF, which are as follows: high VHF, 2.0 db; UHF, 6.8 db.

Table IV shows the reduction in receiver input terminal voltage for the high VHF band and UHF band relative to the low VHF band. The data in columns one and two were derived from the last two columns in Table II and assume the use of a 30-foot length of transmission line as in an average installation. Table IV, columns 3 and 4, shows how these figures are modified, as far as the signal-to-noise ratio in the picture is concerned, by the receiver noise factors. In fringe area installation the antenna usually is mounted on a tower high above the roof. In such cases the length of transmission line required might well be 60–100 feet. For a 60-foot length of transmission line the figures in column 3 of Table IV would be 8.3 db and 24.0 db; those in column 4 would be 10.7 db and 31.4 db. For a 100-foot length of line the figures in column 3 of Table IV would be 8.7 db and 25.1 db; those in column 4 would be 12.5 db and 37.3 db. Thus it can be seen that the UHF receiver is under a heavy handicap as compared with a VHF receiver from the standpoint of signal-to-noise ratio in the picture. This could be offset by increasing the UHF antenna gain and decreasing the transmission line losses. However, the margin for improvement in these respects does not seem to be especially significant considering the magnitude of the required improvement. A decrease in UHF receiver noise factors would be equally effective in improving the performance. However, data obtained on tubes and other electron devices, to be discussed later, show that the magnitude of the possible improvement which could be obtained by using an RF amplifier tube is sufficient to provide only a small part of the required improvement.

There is little difference between VHF and UHF receivers with respect to cross-modulation, as is shown in Figs. 1 and 2.

On the positive side, it should be mentioned that experience has shown that UHF receivers are less susceptible to airplane flutter and to various types of electrical disturbances, both natural and man-made, than are VHF receivers.

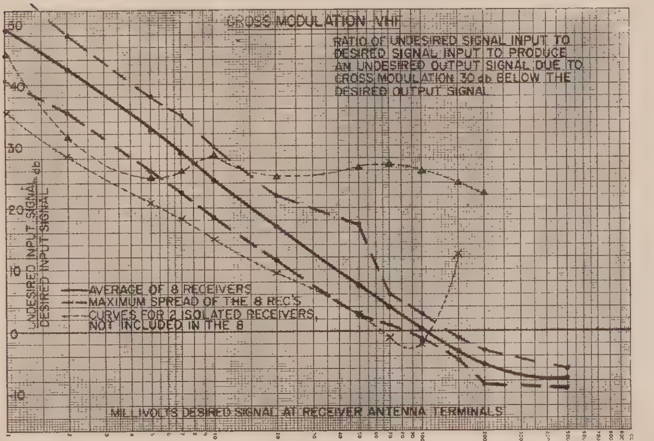

Fig. 1.

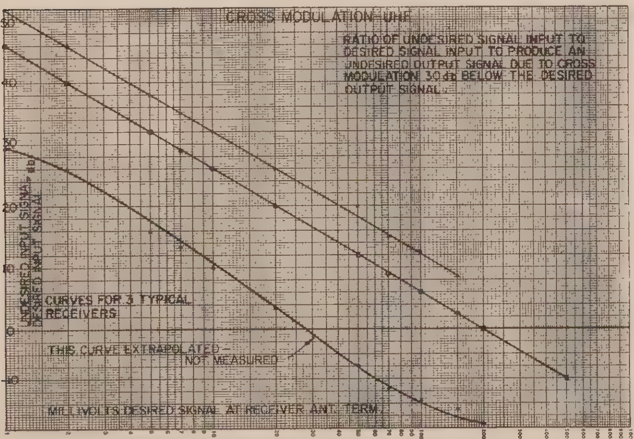

Fig. 2.

ELECTRON DEVICES FOR TELEVISION TUNERS

All of the tubes and semiconductors now being used by TV tuner and set manufacturers were reviewed and tables of data considered pertinent to the performance of these devices in their functional applications were derived. Accordingly, tables were composed listing every tube type now being used in volume in new tuners. In addition, tubes designed for tuner applications at UHF and VHF, but whose commercial TV usage has not yet developed, were added to the lists in order to give an up-to-date picture of the performance capabilities of these devices. The tables are as follows:

Table V.—VHF RF Amplifiers
Table VI.—VHF Oscillator-Mixers
Table VII.—UHF Oscillators
Table VIII.—UHF RF Amplifiers
Table IX.—UHF Mixers
Table X.—UHF Semiconductor Mixers.

These six classifications cover the functional application areas of electron devices used in tuners, and for the purposes of the performance descriptions of products were considered adequate.

Performance Criteria and Technical Data

In the performance tables no attempt was made to provide complete technical information regarding the various electron devices listed since such information is widely available in detail far beyond the scope of this paper. Rather, those electrical characteristics believed to have the greatest significance to the functional applications described in the table headings were selected. In some cases, measurements were made and data presented under "typical" operating conditions rather than under the more normal "rated" conditions for the electron devices under consideration. For example, VHF-RF amplifier tubes were all tested for transconductance (G_m) under typical tuner operating conditions rather than at standard "rated" values of E_b, E_{c2}, I_b and $-E_{c1}$. Thus the relative transconductances and calculated performances derived from these data are considered to represent actual "in-tuner" performance more closely than might otherwise be the case.

The following is a summary of the performance characteristics to be found in Tables V through X:

1) *VHF-RF amplifiers (data in Table V)*:

a) Gain-bandwidth figure of merit. This is determined by calculation from the formula

$$\text{G. B.} = \frac{G_m}{2\sqrt{C_{\text{in}} \times C_{\text{out}}}}$$

where G_m is the low frequency transconductance, C_{in} is the capacitance from G_1 to $K+H$, and C_{out} is the capacitance from P to $K+H$. It should be noted that this figure of merit does not involve frequency-sensitive parameters and consequently can be misinterpreted. This relative value is valid only when the frequency of operation is such that the input resistance of the tube is high. *In this column larger numbers generally indicate better performance.*

b) Theoretical noise factor—at 50 mc and 200 mc. The theoretical noise factor of a vacuum tube is an expression of the irreducible noise generated by the noncorrelated flow of electrons within the tube. This factor, expressed in db, represents the power ratio of the noise produced by the device being tested to that obtained from an ideal "noiseless" amplifier. In our case, we have

TABLE V

VHF RF AMPLIFIERS

Tube Types in Current Usage	Type Class				Cutoff		Heater Current Versions Available				VHF Characteristics								Static Characteristics				Catalog Price
																				With Shield			
	Cascode	Triode	Tetrode	Pentode	Sharp	Remote	6 Volt I_f in ma	300 ma	450 ma	600 ma	Gain Bandwidth[2]	Theoretical Noise Factor at 50 mc-db[3,7]	Theoretical Noise Factor at 200 mc-db[3,7]	Input Resist. 50 mc-ohms[4]	Input Resist. 200 mc-ohms[4]	Equivalent Noise Resist. ohms	Feed Through Cap.-μμf (with shield)[5]	Upper Freq. Limit-mc[6]	G_m-μmhos[7]	G to (K+H)-μμf Capacitance	P to (K+H)-μμf Capacitance	G to P-μμf Capacitance	
6BC5				X	X			X		X	735	3.8	7.4	7,100	500	1,025	0.02	360	7,500	6.6	2.6	0.02	1.17
6BC8	X					X	400			X	2,650	1.7	3.6	10,000	835	340	0.008	500	9,600	2.5	1.3	1.4	2.01
6BK7A	X				X				X	X	2,040	1.8	4.8	6,900	400	355	0.004	380	8,690	3.0	1.5	1.8	1.76
6BK7B	X				X				X		2,040	1.8	4.8	6,900	300	355	0.0043	320	8,700	3.0	1.5	1.8	1.76
6BN4		X			X		200		X	X	1,606	2.0	5.3	9,400	800	460	1.2	530	9,000	3.2	1.4	1.2	1.23
6BQ7A	X				X		400			X	2,410	1.9	5.0	9,400	800	460	0.005	510	8,520	2.6	1.2	1.2	1.98
6BS8	X				X		400			X	2,610	1.7	4.7	6,300	665	345	0.014	520	9,820	2.6	1.35	1.15	1.96
6BZ7	X				X		400			X	2,480	1.9	5.0	9,300	850	420	0.0045	530	8,780	2.6	1.2	1.2	2.01
6BZ8	X					X	400			X	2,520	2.0	5.2	7,400	480	385	0.015	390	9,980	2.8	1.4	1.3	2.37
6CY5			X		X				X	X	1,090	2.7	6.4	11,000	1,070	835	0.03	710	8,100	4.5	3.0	0.03	1.40
PCC88[1]	X				X						2,495	1.6	4.4	7,000	380	190	0.0012	—	13,700	3.5	1.8	1.4	
E-180F[1]				X	X						1,738	2.3	5.9	4,700	170	320	0.019	—	13,500	7.5	3.0	0.03	

[1] European types with possible future usage.

[2] Gain Bandwidth—a figure of merit defined by formula

$$\frac{G_m}{2\sqrt{C_{\text{in}}\times C_{\text{out}}}}$$

This figure becomes deficient when input resistance becomes low. See Paragraph a), page 1070.

[3] For tube only.

[4] Short circuit input resistance.

[5] Input grid to output plate capacitance.

[6] A relative indication of highest frequency of operation attainable. See Paragraph f), page 1073.

[7] Conditions: $E_{c1}=-1V(R_k=68$ ohms). E_b or E_{c2} adjusted for 15 ma I_k and with plate dissipation within rating. These conditions are for comparison on a common basis.

TABLE VI

VHF OSCILLATOR-MIXERS

Tube Types in Current Usage	Type Class			Heater Current Versions Available			VHF Characteristics as Oscillators and Mixers			Static Characteristics								Catalog Price
										Triode[4]				Pentode or Tetrode[4]				
	Triode Pentode	Triode Tetrode	Common Cathode	6 Volt I_f in ma	300 ma	600 ma	Resonant Frequency (mc) Measured[1]	Relative Mixer Gain Zero-Bias G_m (μmhos)[2]	Loading (Feed-back) (μμf)[3]	G_m (μmhos)	G to (K+H) Capacitance (μμf)	P to (K+H) Capacitance (μμf)	G_1 to P (μμf)	G_m (μmhos)	G to (K+H) Capacitance (μμf)	P to (K+H) Capacitance (μμf)	G_1 to P Capacitance (μμf)	
6AT8A	X		X	450		X	930	5,700	0.06	6,500	2.4	1.0	1.5	5,500	4.8	1.6	0.06	1.62
6BR8A	X			450		X	772	5,500	0.008	8,500	2.5	1.0	1.8	5,200	5.0	3.5	0.008	1.65
6CG8A	X		X	450		X	870	5,700	0.02	6,500	2.4	1.0	1.5	5,500	4.8	1.6	0.02	1.62
6CL8A		X		450		X	794	6,500	0.01	8,000	2.7	1.2	1.8	6,400	5.0	3.4	0.01	1.62
6CQ8		X				X	671	5,800	0.015	8,000	2.7	1.2	1.8	5,800	5.0	3.3	0.015	1.65
6EA8	X			450		X	694	7,300	0.01	8,500	3.2	1.1	1.7	6,400	5.0	3.4	0.01	
6EH8	X			450			708	6,100	0.012	7,500	2.8	2.2	1.8	6,000	4.8	3.2	0.012	
6U8A	X			450		X	694	5,500	0.006	7,500	2.5	1.0	1.8	5,000	5.0	3.5	0.006	1.65
6X8	X		X	450		X	990	5,700	0.06	6,500	2.4	1.0	1.5	5,500	4.8	1.6	0.06	1.62
6EU8[5]	X			450		X	694	7,300	0.01	8,500	3.2	1.1	1.7	6,400	5.0	3.3	0.015	

[1] A relative indication of the highest frequency of operation attainable (in oscillator section).

[2] G_m measured at zero bias considered significant. Conditions: $E_{c1}=0$, $E_{c2}=70$ volts, $E_b=100$ volts.

[3] Considered as a function of capacitance between the input signal grid and output plate.

[4] Capacitances measured with external shield.

[5] The 6EU8 differs from the 6EA8 in base connections.

TABLE VII

UHF OSCILLATORS

Tube Types in Current Usage	Type Class	Heater Current Versions Available			Oscillator Characteristics	Static Characteristics				Catalog Price
	Triode	225 ma 6 volt	450 ma	600 ma	Resonant Frequency[1] (mc)	G_m (μmhos)	Input Capacitance[2] G_1 to $(K+H)$ (μμf)	Grid-Plate Capacitance[2] (μμf)	Output Capacitance[2] P to $(K+H)$ (μμf)	
6AF4	X	X	X	X	1,345	6,500	2.2	1.9	1.4	2.01
6AF4A	X	X	X	X	1,408	6,500	2.2	1.9	1.4	2.01
6T4	X	X			1,343	7,000	3.3	1.7	1.8	2.01

[1] Cold line test. Considered a relative indication of the highest frequency of operation but not necessarily the highest attainable.
[2] Capacitance measured with external shield.

TABLE VIII

UHF RF AMPLIFIERS

Tube Types Considered[1]	Type Class	UHF Characteristics						VHF 200 mc Characteristics		Static Characteristics				Catalog Price
	Triode	Power Gain—db (measured) (500 mc)[2]	Power Gain—db (measured) (900 mc)[2]	Noise Factor—db (500 mc) (measured)	Noise Factor—db (900 mc) (measured)	Approximate Input Resist. (ohms) Grounded Grid (900 mc)	Equivalent Noise Resistance (ohms)	Noise Factor—db	Power Gain—db	G_m (μmhos)	Grid to $(K+H)$ Capacitance (μμf)[3]	P to G Capacitance (μμf)[3]	P to $(K+H)$ Capacitance (μμf)[3]	
6AM4	X	7.1	7.0	13.2	14.0	100	340	8.1	12.0	9,800	3.2	2.2	0.22	2.99
6AN4	X	12.0	10.0	12.0	14.0	100[4]	300	6.5	14.0	10,000	2.6	1.7	0.18	2.54
6BC4	X	10.0	6.0	11.5	14.5	100[4]	300[1]			10,000	2.9	1.6	0.26	2.49
6BY4	X	15.0	15.0	7.5	8.5	180	500	4.2	14.0	6,000	1.2	0.7	0.007	—
6299	X	15.5	15.0	5.5	8.0	100	175	3.7	16.0	12,000	3.5	1.7	0.015	56.00
6BA4	X	14.0	14.0	8.0	11.0	125	400[1]			8,000	2.4	1.4	0.02	39.25
5876	X	11.7	14.0	9.4	12.5	150	500			6,500	2.5	1.4	0.035	13.55
7077	X	14.5	14.5	5.5	7.5	150	350	2.7	14.5	9,000	1.9	1.0	0.01	—

[1] Types shown are not in current usage. The list is being retained to provide technical information to TASO.
[2] Gain measurements with the minimum of 10-mc bandwidth.
[3] Capacitances as published with grounded-grid connection.
[4] Calculated. Data shown for other types are measured.

TABLE IX

UHF MIXERS

Tube Types Considered[1]	Type Class	Static Characteristics				Catalog Price
	Triode	G_m (μmhos)	G to $(K+H)$ Capacitance (μμf)	P to G Capacitance (μμf)	P to $(K+H)$ Capacitance[2] (μμf)	
6AM4	X	9,800	3.2	2.2	0.22	2.99
6AN4	X	10,000	2.6	1.7	0.18	2.54
6BC4	X	10,000	2.9	1.6	0.26	2.49
6BY4	X	6,000	1.2	0.7	0.007	

[1] Types shown are not in current usage. The list is included to provide technical information.
[2] Grounded-grid with shield.

TABLE X

UHF SEMICONDUCTOR MIXERS

Types in Current Usage	750-mc Over-all Noise Figure ($NF_{if}=3.5$ db)	Conversion Loss	Output IF Impedance at 40 mc	Catalog Price
1N82A	13.0 db	8.0 db	400 ohms	0.98
1N72	13.0 db	8.0 db	400 ohms	0.87
1N124A	13.0 db	8.0 db	400 ohms	
1N147	13.0 db	8.0 db	400 ohms	

NOTE: Crystal Current = approximately 0.75 ma. These data are presented as family characteristics. See Paragraph 6), page 1074.

followed the method of Rothe[5] to make measurements,[6] at 90 mc, of the noise parameters of the tubes listed in the table. From these the noise factors can be calculated. The values shown in the tables are the lowest values of noise factor one may obtain from each of the types listed under the test conditions specified. *Low noise factor is regarded to be desirable for RF amplifier applications.* It should be noted that in practical applications the over-all tuner noise factor is generally 2 to 3 db greater than the values shown in the table because of circuit limitations. Noise factor is sensitive to operating conditions. The data presented are not necessarily under optimized conditions.

In a practical case it should be noted that the correlated noise usually cannot be eliminated completely, at least with today's techniques. For this reason, the theoretical noise factor listed in Table V will not be realized. In combination with other parameters, a listing of tubes in order of merit may be somewhat different when considering correlated noise than when not considering it.

c) Input resistance—at 50 mc and 200 mc. This important parameter is an indication of the apparent electrical resistance one may measure between the input grid and cathode at the frequency indicated. Since this value of resistance appears as a loading factor on the tuned circuits usually associated with RF amplifier stages, *a high value of input resistance, i.e., least loading of tuned circuit, is considered desirable.* Values of input resistance shown in Table V were measured under "rated" operating conditions given in the tube manuals. The values shown are averages obtained from measurements made on tubes manufactured by several different companies. This characteristic is quite dependent upon operating point (I_b, E_b, $-E_{c1}$) and frequency. (Input resistance is approximately proportional to $1/(\text{frequency})^2$ in the UHF and VHF range.)

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[5] H. Rothe and W. Dahlke, "Theory of noisy fourpoles," PROC. IRE, vol. 44, pp. 811–818; June, 1956.
[6] C. Metelmann, "Noise Measurements by the Rothe Method," presented at the AIEE Winter General Meeting, New Hork, N. Y.; January 21, 1957.

d) Equivalent noise resistance. This value of resistance referred to the input network is one of the parameters by which the noisiness of an electron device can be described. This value of resistance, which can be determined experimentally by the use of Rothe's theory,[5] will produce the same noise energy at room temperature as the electron device being measured. Tubes having *low values of R_{eq} are generally better* than those having high values. An approximate method for calculating an equivalent noise resistance for triodes is given by the formula

$$R_{eq} = \frac{2.5}{g_m}.$$

Experience has shown that this figure is sometimes seriously in error, and considerable care must be taken in applying calculated values.

The Rothe method for determining the R_{eq} has been applied to the measurements in Table V because it has been determined to give accurate results.

e) Feedthrough. This is a value of capacitance measured from output plate to input grid of the RF amplifier. This capacitive reactance provides a coupling path for oscillator voltage to appear on the input tuned circuits. Therefore, the *feedthrough capacitance should be as small as possible* for best results in TV applications.

f) Upper frequency limit. This is a calculated value of the frequency at which the product of the input resistance and the transconductance equals unity, $G_m \times R_{in}(f) = 1$. Since the input resistance is proportional to $1/f^2$ approximately, this calculation for frequency can be made by simple arithmetic if the G_m is known and an accurate value of R_{in} at some frequency has been determined.

One must recognize that this upper frequency limit is an expression of considerable significance. The numbers shown here are probably somewhat higher than could be realized in practical tuners. *High values of upper frequency limit are desirable.*

g) G_m—transconductance. This characteristic is regarded as one of the more significant of amplifier tube parameters. The data reported in Table V were determined by operating the tubes under operating conditions typical of TV tuner applications rather than under "rated" conditions specified by the tube industry. In order to compare tube types, measurements were made under the same operating conditions.

All G_m measurements (1000 cps) listed in this column were made at $I_p = 15$ ma; $R_k = 68$ ohms (yielding a bias of -1.02 volts); and E_b adjusted to give the proper I_b. The tetrodes and pentodes were operated at $I_K = 15$ ma with the screen grid at plate potential. The transconductance of the cascode triodes was measured in a series-cascode connection with G_m of the input section being measured and recorded. *High values of G_m are desirable.*

h) Catalog price. In each of the tables a column of catalog price is included to enable the reviewer to determine the relative "net" price for which these tubes can be purchased. The committee arbitrarily selected a widely distributed 1958 catalog as the source of this information. Wherever price information is not included, no price was available from the catalog chosen.

2) *VHF oscillator mixers (data in Table VI).* Current practice in VHF tuner design is to employ a triode-pentode or triode-tetrode tube as a single-tube oscillator-mixer. The triode section of the tube functions as the local oscillator which supplies a signal to the other section of the tube for the purpose of converting the VHF signal to an intermediate frequency, usually 40 mc. In the performance evaluation of these electron tubes, the following characteristics are considered as definitive:

a) Resonant frequency measurement. This is the frequency at which the internal structure, including the base leads, becomes resonant. While this frequency is not necessarily the highest frequency at which the tube can be made to oscillate by the use of appropriate circuit components, the values indicated in Table VI provide relative indications of the maximum frequencies of these tubes. *A high resonant frequency is desirable.*

b) Gain—relative. This figure is an indication of the relative mixer section gain which may be realized from the tube under test. This measurement is a static, rather than a dynamic, test of the zero-bias transconductance of the mixer section. The mixer conversion transconductances, obtained under dynamic conditions, are approximately one-fourth of the values shown here. *A high value of zero-bias G_m is desirable.*

c) Loading (feedback). This value of capacitance represents the undesirable coupling which exists between the output plate of the mixer and its input grid. *A low value of loading is desirable.*

d) Static characteristics. The static characteristics of VHF oscillator-mixers deemed most significant are listed under this heading. *In general, high transconductances (G_m) and low interelectrode capacitances are the desirable features of these tubes.*

3) *UHF oscillators (data in Table VII).* Only three tubes are in current usage as UHF oscillators. These are all triodes and are characterized by a high resonant frequency. These tubes are physically small in order to keep capacitance and lead inductance low, and are re-

quired to supply a few milliwatts of power to the mixer stage of UHF tuners.

4) *UHF-RF amplifiers* (*data in Table VIII*). None of the tube types listed is being used in TV tuners for home use at the present time. The first three tubes on this table are of miniature construction, while the remaining tubes employ special construction techniques designed to yield superior UHF performance.

a) Gain measurements—at 500 and 900 mc. These figures are expressed in decibels for the condition of power matched impedances. Since the circuit and the tube are so intimately related at UHF, no attempt has been made in this table to separate the performance characteristics of each as was done at VHF. A number of different circuit configurations of the grounded-grid type were used. *A high value of power gain is desirable.*

b) Noise factor. This is an expression, in db, of the noisiness of the amplifier stage under test. The noise factor is determined primarily by the characteristics of the electron device being used. Since the UHF tube or semiconductor employed acts as a generator of unwanted noise signals, the basic UHF performance of the equipment, that is, its ability to receive weak signals, is dependent upon this factor to a considerable extent. Methods of measuring this characteristic are complex; however, by using a calibrated noise generator, such as a noise diode or argon discharge lamp and a calibrated amplifier, a relatively accurate determination of noise factor can be made. It should be noted that noise factors at UHF were measured at the frequencies stated. This is different from the VHF noise factors which were calculated. *Low values of noise factor are desirable.*

c) Approximate grounded-grid input resistance. All of the triode tubes listed are intended for application in grounded-grid circuits. Accordingly, the approximate input resistance of the stage is determined by the transconductance of the tube and is nearly $1/G_m$. Maximum power gain is obtained when the source resistance is approximately equal to this value. Minimum noise factor may be obtained at some other values of source resistance.

d) VHF characteristics of UHF tubes. It should be noted that all UHF triodes are capable of very effective operation at VHF.

e) Catalog price. The last five types shown in Table VIII, employing special construction, are somewhat more costly than the more conventional types.

5) *UHF mixers—vacuum tube.* No UHF vacuum tube mixers are now being used for TV (home use) tuners. The types listed in Table IX have been tested in laboratories and have been found to be applicable to this type of circuit.

6) *UHF Mixers—semiconductor.* The types in current usage are listed in Table X. In addition to these types, a few others are known to be in limited use. The performance figures shown represent average crystal mixers in average tuners. *All UHF-TV tuners in current production use crystal mixers.* A wide variety of applications, some involving double conversion, or harmonic oscillator drive, have been noted in addition to the usual single conversion (to 40 mc) applications. Semiconductor mixers have a conversion loss of about 8 db as noted and provide low impedance drive to the IF amplifier.

Interpretation of Data

It is evident from the foregoing discussion and the data contained in the tables that a great many factors enter into the selection and application of electron tubes and semiconductors for TV tuners. The most salient technical characteristics have been covered to some extent. Nonetheless, other factors should be considered in weighing this technical information. One could generalize and state that the functional requirements of electron devices for TV tuners appear in the following possible order of importance:

1) Noise factor—should be low.
2) Amplification (sensitivity)—should be high.
3) Oscillator stability—frequency of oscillation should be constant.
4) Dynamic range.
    a) Gain control—should be widely variable without introduction of distortion or increase of over-all signal-to-noise ratio.
    b) Cross-modulation—low so that desired weak signals are not distorted in presence of undesired strong signals.
5) Efficiency of operation—should be high to minimize power input requirements.

Fig. 3 is a plot of noise factor vs frequency in which the theoretical noise factors for electron devices, as reported in the appropriate tables, and the measured noise factors of receivers are given. It should be recognized that these data represent laboratory measurements in which the effects of galactic noise and noise from other sources, such as ignition noise, radiation effects from industrial equipment, lighting devices, etc., have been excluded. Since most of these sources of noise exhibit decreasing output as frequency increases, the effective performance of receivers, particularly in the VHF region, may deviate greatly from the values shown in Fig. 3. Two reports demonstrating the frequency sensitive nature of these types of noise[7,8] were considered in detail and reported to TASO Panel 2 for additional consideration by the TASO organization. When these additional noise sources are considered, it is apparent that the items listed above may not be in the order of greatest importance for all receiving locations. Nevertheless, these five items are regarded to be the major technical areas of consideration in the application of electron devices to TV tuners.

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[7] K. Bullington, "Radio propagation fundamentals," *Bell Sys. Tech. J.*, vol. 36, pp. 593–626; May, 1957.

[8] D. V. Carlson, "Galactic Noise—An Important Design Consideration of VHF Television Tuners," RCA Industry Service Lab., Rept. No. LB-1068; April 4, 1957.

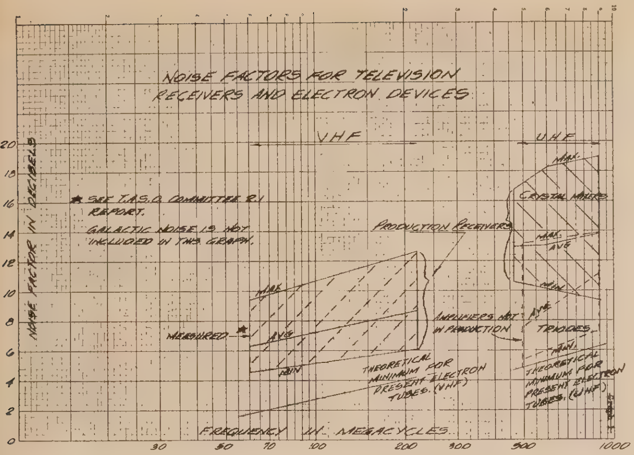

Fig. 3.

It should be recognized that some characteristics of electron devices, combined with circuit elements of the tuners in which they are used, account for important performance attributes of these tuners. In most cases, the data reported in the foregoing tables do not include parameters which are normally associated with circuit design considerations such as capacitance from heater to cathode. As was mentioned earlier in this paper, only those characteristics completely identifiable with the electron device being evaluated are listed, and distinct efforts have been made to prevent these data from reflecting circuit considerations which are outside the control of the tube or diode manufacturer.

In summary, it appears that in the VHF region available vacuum tubes are capable of providing generally adequate tuner performance in at least the first three technical areas listed above. In the UHF region, electron devices are available to perform the functional requirements of tuner operation; however, present practice embodies only the use of vacuum tube oscillators and crystal mixers with performance results as shown in Fig. 3. By employing vacuum tubes designed for UHF applications as RF amplifiers, considerable performance improvement could be realized. However, it should be noted that tubes capable of providing this improved performance are relatively very expensive and for some time have been regarded as lacking economic justification for consumer product applications.

At UHF, oscillator stability has been recognized as one of the major technical problems to be solved. Engineering work has been done on both the tubes and the circuits in which they are used, and improvements have been made by the various manufacturers in both of these areas. Although long-term life test data were not available in sufficient quantity to draw industry-wide conclusions, it was recognized that somewhat higher cathode loading, leading potentially to shorter operating life, is required from UHF oscillator tubes than from VHF oscillator tubes.

Data presented in the tables show that the performance/price ratios for tubes used at VHF are higher than those for tubes designed for UHF applications. Where economic factors must be given consideration, it is reasonable to consider the present status of the performance/price ratios as reflecting the inherently more costly nature of high-performance UHF tubes. It is beyond the scope of this paper to speculate on the changes which might be anticipated in this situation should wider interest develop in UHF applications.

Regarding transistors, there is no commercial use of transistors in TV tuners at VHF or UHF. Laboratory tuners using transistors have been built and tested which would receive VHF signals and convert them to IF for further amplification. No similar work at UHF was discovered. No performance information on VHF applications was available.

Community Antennas and Distribution Systems

Community antenna and distribution systems provide television service to communities spreading across the entire country. These communities range in population from a few hundred to about 50,000.

According to a recent report,[9] there were 610 community antenna systems in operation. Not all operators reported the number of homes they serve, but those giving figures reported a total of 492,345 subscribers, with a potential of 934,864. The number of subscribers per system averages 1056, with a potential average of 2068. One system with 900 subscribers and a potential of 1500 was in operation in Alaska.

Information collected from the field shows that of the 125 community television systems providing information on the number of channels received and the distances to the transmitters, 24 systems reported the reception of UHF signals and seven received some of their signals via microwave relay. Fig. 4 shows the distribution of distances over which the 125 systems receive the signals which they use—VHF, UHF and microwave relay.

Fig. 5 was based on the data on UHF signals reported by the 24 systems and shows the distribution of transmission distances involved. It is hoped that a comparison of these data with data obtained by TASO committees involved in propagation studies might be useful in determining distances over which satisfactory UHF signals might be received for Community Antenna Television (CATV) use. In this connection it should be observed that there are some differences between the forms of the propagation data which would be applicable to the CATV reception problem and to the usual service area or interference area. Such data are often presented in the form using the statistical parameters $A(B, C)$ where A is a field strength, quite low in interference areas and moderate to high in service areas; B represents a percentage of locations at which this field strength is exceeded C per cent of the time. Both B and C are relatively high in service areas (50 per cent and

[9] *Television Digest*, vol. 14, p. 2; September 20, 1958.

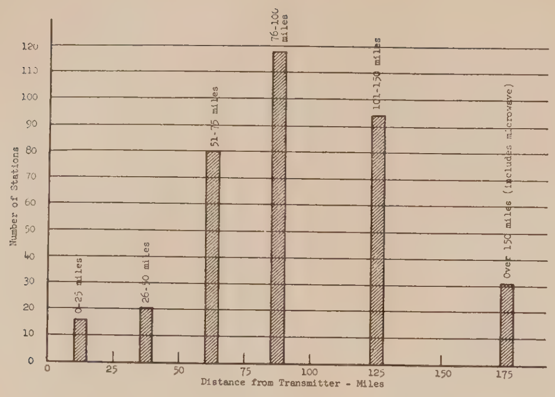

Fig. 4—Total number of stations (VHF, UHF and microwave relay) used by 125 community antenna television systems vs distance.

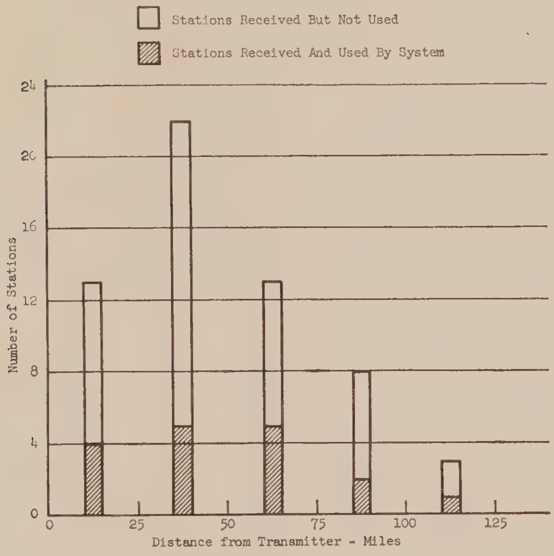

Fig. 5—Number of UHF stations reported received by 24 community antenna television systems vs distance.

higher for *B* and 90 per cent for *C*) and low in interference areas.

In the locations where CATV systems are likely to fill a need, the values of these parameters are somewhat different. For example, *A* needs to be moderate, *B* is likely to be quite low, and *C* should be high.

The data presented in Figs. 4 and 5 indicate that reception distances for this type of signal area for UHF are likely to be considerably less than for VHF operations, although exact numerical data might be difficult to obtain. To some degree, the difference in reception distances may be due to the fact that most community TV systems have relied largely on VHF signals up to now.

In order to determine the possible impact of a restriction in reception range, the data provided in the questionnaire were assembled as shown in Fig. 6. In this figure, the original data were arranged to show what would happen to the 118 systems using off-air reception entirely if the usable range of the stations which are presently used were dropped to specific distances of 25, 50, 75, 100 and 150 miles. It will be noted that there would be a continuous decrease in the number of systems which could receive any signals at all, as well as an increase in the number which would be restricted to carrying only one or two channels. Since the economics of system operation depends in some cases on the number of channels available for distribution, this could represent a more rapid decrease in the number of systems which it might be feasible to operate. The most rapid decrease occurs in the region of a 75-mile maximum range which coincides very closely with the most rapid decrease in UHF reception reported.

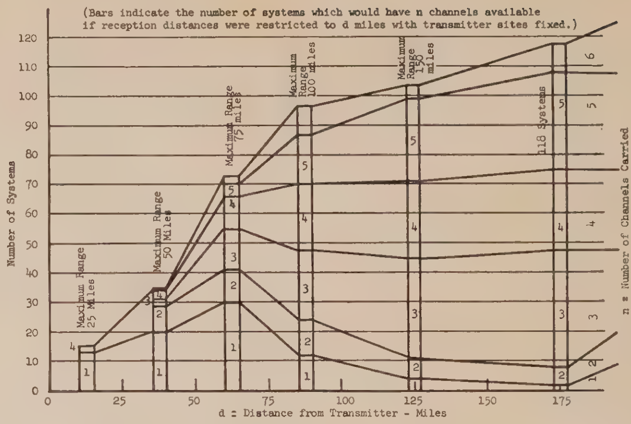

Fig. 6—Chart indicating effect on 125 community antenna television systems if reception distance were restricted.

The data appear to indicate that a shift in frequency of the transmitters involved would have a considerable impact on the operation of community antenna systems. A large number of communities would lose service entirely and the operations of another large group would be severely restricted. This impact could probably be reduced somewhat by recourse to microwave relay or similar service to obtain signals. However, economic factors here are fairly complicated. It appears likely that a large number of the systems first affected by a reduction of transmission range would be the smaller systems serving communities of a few hundred. The cost of relay service would be out of the question for many of these unless a service, common carrier or private, using less expensive installations were made available.

EFFECTS OF TRANSMITTER SOUND POWER REDUCTION ON RECEIVER PERFORMANCE

Tests were made on representative television receivers to determine the effects of a reduction in sound power on the performance of television receivers. The receivers used in these tests included the various types of sound detector circuits currently in use; the results obtained are therefore felt to be representative of those which can be expected in the field using new, aligned receivers of modern design, properly installed.

The following types of tests were made in order to determine the extent to which receiver performance was affected or modified by a reduction in transmitter sound power below the value currently standardized, *i.e.*, between 50 and 70 per cent of the peak visual power:

Thermal noise (signal-to-noise ratio)
Impulse noise rejection.

Additionally, consideration was given to the problem with respect to:

Loss of service area
Adjacent-channel interference
Fine-tuning characteristics
Fading
Co-channel interference
Sound vs picture performance.

It has been the experience of receiver manufacturers since receivers were first put on the market that there has been an ever-present demand for greater sensitivity. Users in fringe areas are, in many cases, willing to install receivers at considerable expense provided a good, reliable sound signal can be obtained even though the picture performance may be subject to fading, interference, impulse or thermal noise of a magnitude such as to cause serious picture degradation, or even a loss of picture from time to time. In such areas a reduction in sound power would result in serious impairment of service and in many cases a complete loss of service.

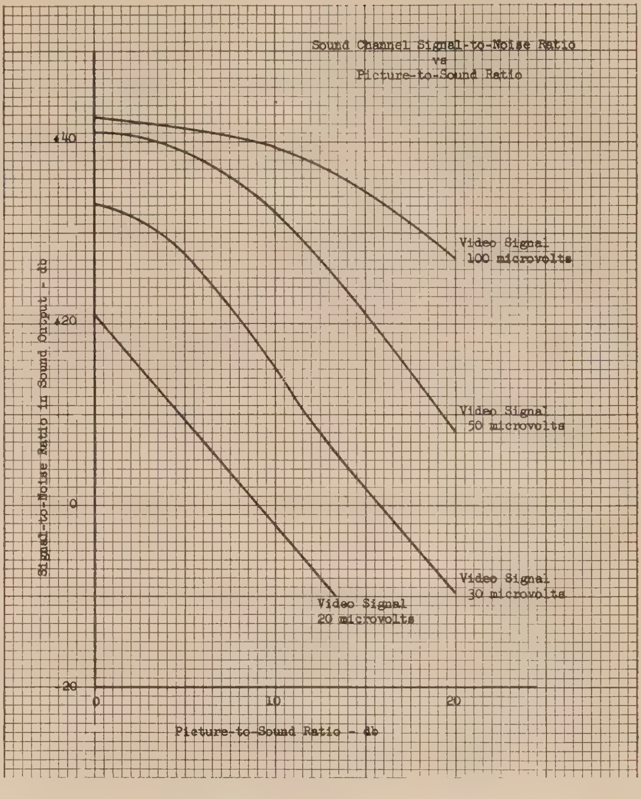

Fig. 7.

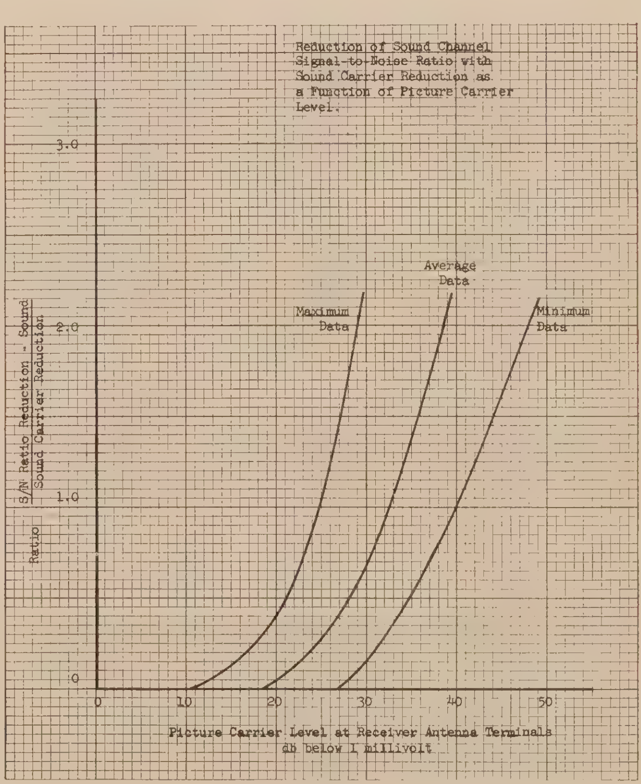

Fig. 8.

Thermal Noise Performance

A reduction in transmitted aural power will result in poorer receiver signal-to-thermal-noise ratio which will, by reduction of receiver fringe area sound performance, reduce the sound coverage of any given transmitter. To obtain experimental verification of the reduction of sound channel thermal noise performance, measurements were made on nine different receivers. Four different types of FM detector systems are represented in these receivers covering every type in use today. In all cases, measurements are for one of the lower VHF channels. Fig. 7 presents the data of one of these receivers which is typical of the group. Sound channel signal-to-noise ratio is plotted as a function of picture-to-sound ratio for a number of picture carrier signal levels. It can be seen that for each signal level there is a threshold value of picture-to-sound ratio below which the signal-to-noise ratio degrades rapidly. Fig. 8 presents a summary of these data for all the measured receivers. The loss of sound channel signal-to-noise ratio per unit reduction in sound carrier is plotted as a function of picture carrier level. In these data the average of all the receivers is presented and the data for the measured extremes are also plotted. As an example, from this curve it can be seen that with 20 microvolts (−34 db) of picture signal (open-circuit antenna voltage delivered through a 300-ohm dummy antenna to the receiver), an average loss of about 1.5 db in signal-to-noise ratio will occur for each db of aural carrier power reduction. These data are for new, aligned receivers of modern design. If we add the losses expected due to misalignment, tube aging and antenna orientation and mismatch, as well as transmission line losses, it is reasonable to expect that this type of signal-to-noise ratio loss would occur in the 100 to 200 microvolts-per-meter range of signal strength in a substantial number of receivers currently in the hands of the public.

Sound quieting sensitivity, which takes into account only thermal noise considerations, is 30 microvolts for the typical receiver in the group used to obtain these data. As can be seen from Table III, the picture sensitivity for 78 receivers reported varied from four to 150 microvolts. The distribution of sensitivity shows:

12.8 per cent—less than 10 microvolts
34.6 per cent—between 10 and 20 microvolts
19.2 per cent—between 20 and 30 microvolts
11.5 per cent—between 30 and 50 microvolts
9.1 per cent—between 50 and 100 microvolts
12.8 per cent—greater than 100 microvolts.

The importance of fringe area performance may be judged by the fact that more than 66 per cent of the receivers reported picture sensitivities better than 30 microvolts.

Impulse Noise Rejection Performance

A common form of noise interference in the sound channel is that caused by automotive ignition noise, electric motor commutator noise (shavers, mixers, vacuum cleaners, etc.), arcing switches, and lightning. This form of noise is usually lumped under the general heading of impulse noise. In order to measure the effect of aural carrier power reduction on receiver performance in the presence of this form of noise, an interference source, such as a nonsynchronous 60-cps rotating arc device, was coupled through a variable attenuator into the antenna circuit of the test receiver in parallel with the desired standard visual and aural television signal. The interference noise signal input to the receiver was increased until its presence was noted in the sound output of the receiver either by aural or measured output detection. The aural signal was then reduced in steps and at each step the change in noise interference required to restore the original condition was recorded. Data were obtained on seven different commercial receivers. Data for a typical receiver are plotted in Fig. 9 for visual signal input levels ranging from 50 to 10,000 microvolts. Fig. 10 presents a plot of data for the relative impulse noise level for constant audible interference as a function of sound-picture ratio. This is the average of all data for all seven receivers measured. A loss of tolerance

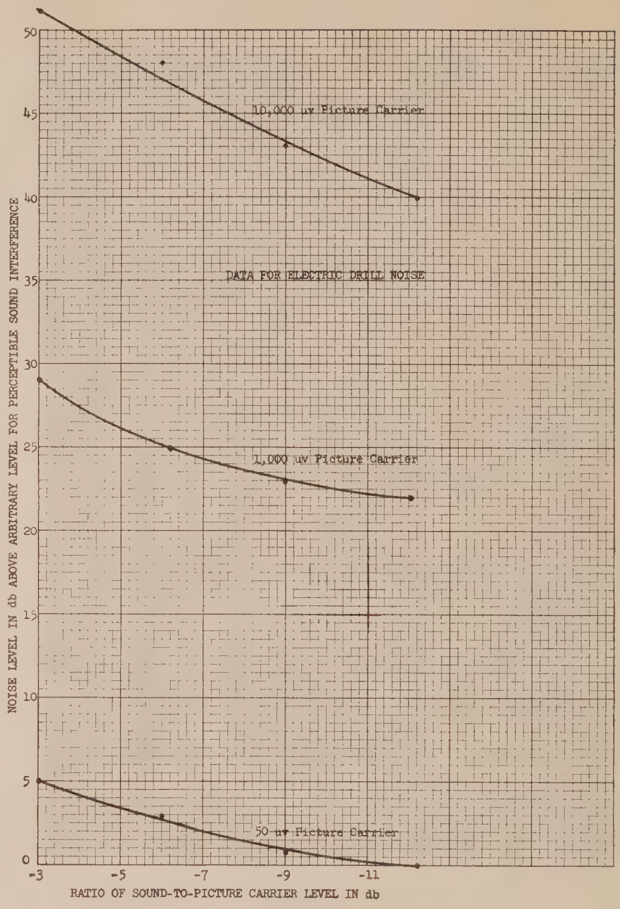

Fig. 9.

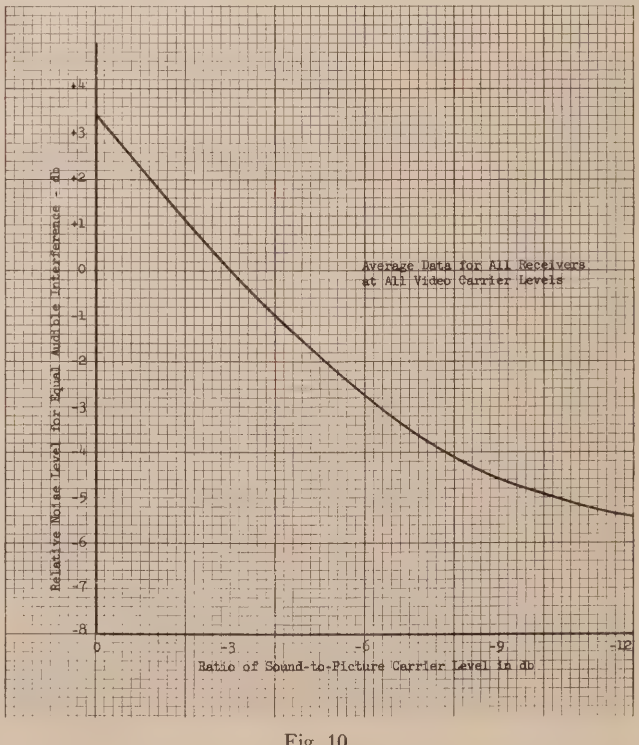

Fig. 10.

to impulse noise of about 1 db for every db of reduction in aural power is noted. This performance loss occurs at strong signals as well as weak; the performance loss with reduction of aural power is as great at 10,000 microvolts as it is at 50 microvolts. As in the previous case for thermal noise, these data are for new, aligned receivers of modern design.

Loss of Service Area

In order to show the loss of service area resulting from a reduction of sound power, the required field strength in db above 1 μv/meter to produce 30 db quieting was determined by measurement of the quieting sensitivity for representative TV receivers under existing transmission standards and calculation of the equivalent field strength. The average figures for antenna gain and transmission line losses were used for channels 4 and 10, which are about in the middle of the two frequency ranges. The required increase in video and sound signal levels to compensate for a reduction in sound power with respect to video power was determined to be 0.57 db for each db drop in sound power. This was obtained from the average degradation in signal-to-noise ratio at the 30-db level in data furnished by the members of this Committee.

Finally, the reception range and loss of service area was determined from the FCC curves of expected field strength, assuming maximum authorized power in the TV transmitter, and representative antenna heights.

Figs. 11 and 12 show the loss of service area for VHF channels 2–6 and 7–13 resulting from a reduction of sound power below the present minimum of 3 db below the peak video power. The service area is reduced about 20 per cent on the low VHF channels and about 10 per cent on the high VHF channels if a 7-db reduction in sound power is made.

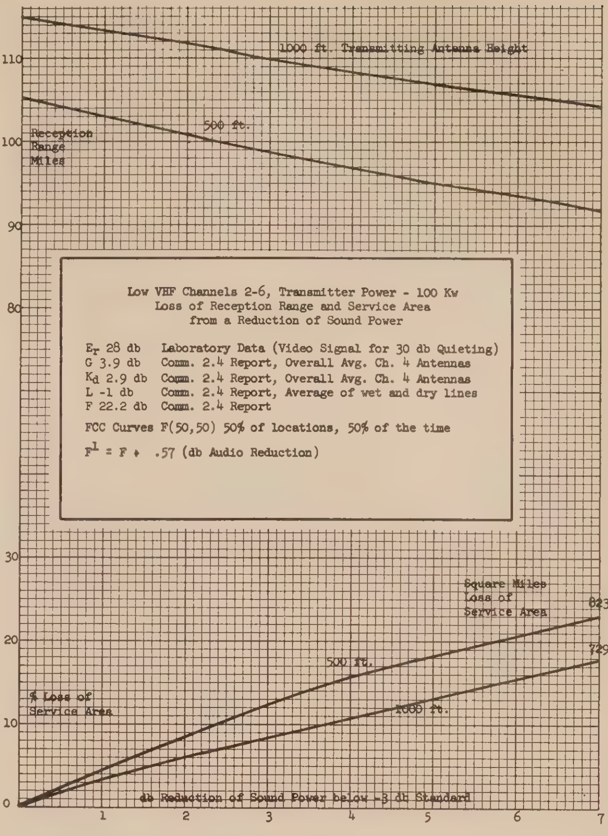

Fig. 11.

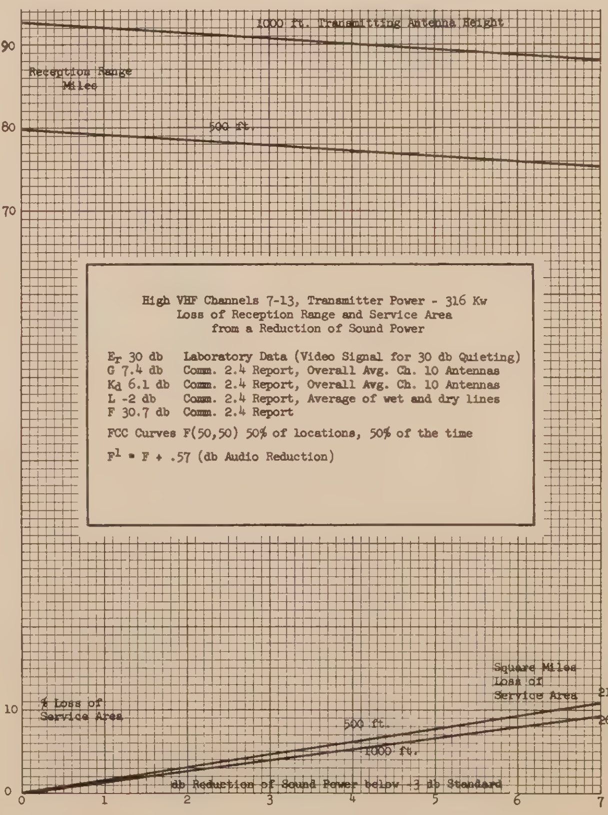

Fig. 12.

Adjacent Channel Interference

A reduction in transmitted aural power would reduce the lower adjacent channel sound interference in those areas where it now exists by an amount equal to the sound power reduction. Examination of the data in Table III shows that receiver attenuations for the lower adjacent channel sound signal vary widely, ranging from 14 db to 60 db. The attenuations are distributed as follows:

11.8 per cent—less than 30 db
42.1 per cent—between 30 and 40 db
13.2 per cent—between 40 and 50 db
32.9 per cent—greater than 50 db.

This wide variation is reflection of the fact that this performance characteristic is determined by competitive pressure in particular areas rather than by a universal requirement.

The fact that competitive pressure determines receiver adjacent channel rejection capabilities in most cases means that for any small variation in adjacent channel interference, such as would be accomplished by a 7-db reduction in sound power, the net improvement would be relatively short-lived, as new designs under economic pressure would tend to seek the same competitive level as is now considered satisfactory. Conversely, any increase in adjacent channel interference, such as might result from a permitted increase in both picture and sound power, might result in no long-term degradation in adjacent channel performance, as competitive pressure would force receiver manufacturers to build more adjacent channel rejection in receivers.

Other factors which are of importance but less susceptible to a quantitative analysis include the following.

Fine Tuning

A reduction in transmitted sound power will result in a more critical requirement for fine tuning in weak signal areas, thus increasing the need for skill and judgment in adjusting the fine tuning control, a function in which most consumers are presently inept.

Fading

A reduction in transmitted sound power will aggravate the effects of fading, either natural or man-made, such as airplane flutter, on the sound performance of the TV receiver.

Co-Channel Interference

In some locations at present both picture and sound reception is limited by co-channel interference. Co-channel picture interference can be considerably improved by operation of all transmitters on the proposed super-accurate offset. In the event of improved picture channel performance by the use of these techniques, reduction of sound channel coverage might nullify the improved picture coverage.

Sound vs Picture Performance

It is the emphatic experience of all television receiver manufacturers that the public will tolerate and be entertained by extremely marginal picture signals provided satisfactory sound signals are available. In the report of the first NTSC in 1941, it is stated, "... a given amount of interference is more disturbing in the sound than in the picture. The service area of the television system will be determined by the acceptability of the service with respect to the noise interference."

Future System Development

Technological advances and improvements could conceivably make use of the sound channel to transmit additional information. A reduction of aural power could obstruct such possible future benefits.

It is considered beyond the proper scope of this paper to hypothesize what design changes might be made by commercial television receiver manufacturers in the future in the event of any change in transmission standards; however, it can be stated that the factors cited with regard to thermal and impulse noise considerations are fundamental to all receiver designs.

In summary, any proposals for sound power reduction should weigh what appears to be a minor and probably short-lived advantage of adjacent channel sound interference reduction against the disadvantage of the fundamental reduction of system capability and coverage.

ACKNOWLEDGMENT

The data and other pertinent information presented in this paper were collected by the members of TASO Panel 2 and its several committees, comprising a total membership of 75 industry engineers. A debt of gratitude is owed to these men.

In particular, appreciation is expressed to the following Panel 2 officers and Committee Chairmen:

G. W. Fyler, Zenith Radio Corporation
K. A. Chittick, Radio Corporation of America
S. P. Ronzheimer, Hazeltine Research, Inc.
D. W. Pugsley, General Electric Company (now with Ramo-Wooldridge Corporation)
R. S. Yoder, Motorola, Inc.
A. W. Bridgett, Spencer Kennedy Laboratories
G. G. Edlen, Entron, Inc.
D. Sillman, Westinghouse Electric Corporation
A. P. Haase, General Electric Company
J. F. McAllister, Jr., General Electric Company
W. P. Boothroyd, Philco Corporation
S. Napolin, Granco Products, Inc.

Findings of TASO Panel I on Television Transmitting Equipment*

H. G. TOWLSON†, SENIOR MEMBER, IRE, AND J. E. YOUNG‡, SENIOR MEMBER, IRE

***Summary*—TASO made a thorough study of the characteristics, performance and cost of television transmitters, antennas and transmission lines, and translators. The results of these studies gives a clear picture of the technical and economic factors involved in operating television transmitters in the VHF and UHF bands. This paper summarizes some of these studies which are reported in detail in the TASO Report, "Engineering Aspects of Television Allocations."[1]**

INTRODUCTION

ANY study of the frequency allocation of television broadcasting involves many parameters. It was the purpose of TASO Panel I to study those having to do with transmitting equipment—to accumulate information for the purpose of appraising both present and potential performance of television transmitters, antennas and transmission lines, translators and other transmitting equipment for both VHF and UHF broadcasting.

At the date of the Panel 1 report there were 448 VHF and 93 UHF broadcast stations in operation, and the cost data developed and presented by Panel 1 show that each of these 541 stations has a considerable capital investment in its plant. Since each plant, if it is to continue operating, must be either immediately or potentially profitable, any study of allocations must include economic as well as technical factors. The first portions of this paper will deal mostly with the cost factors and the latter portions with the technical performance characteristics.

ORGANIZATION OF PANEL 1

Representation on the Panel was secured by invitation to known manufacturers of transmitting equipment and to networks and broadcasting stations, as well as by press releases from TASO headquarters announcing the formation of the panels and inviting participation by interested persons. The committee organization of Panel 1 was set up as follows:

1.1 Committee on Standard Transmitters—charged with studying the characteristics (cost, performance, reliability) of standard TV transmitters, both VHF and UHF.

1.2 Committee on Repeater Transmitters—charged with the investigation of the performance of repeater transmitters.

1.3 Committee on Antennas—charged with the study of the characteristics of antennas, towers and transmission lines.

1.4 Committee on Systems—charged with the study of the applicability of new techniques in transmitter operation.

Attention is called to the term "repeater" transmitters in the title of Committee 1.2. "Repeater" is used to include satellites, translators and boosters. The regular Television Broadcasting Station was classed as a "standard" transmitter under Committee 1.1.

METHODS OF OBTAINING COST INFORMATION

To obtain reliable first hand information considerable use was made of questionnaires. Committee 1.1 sent questionnaires to 490 operating stations to obtain transmitting plant information on their initial and operating costs as well as information on technical performance, outages, etc. Committee 1.3 sent questionnaires to 475 stations to obtain antenna plant information, and the response to these questionnaires was about 55 per cent. Committee 1.2 obtained information on facilities and operating data for translators by means of a questionnaire sent to all translators and to all translated television stations.

Prices on current TV equipment, tube costs, operating powers, etc. were obtained directly from the catalogues of the manufacturers of transmitting equipment. At first, Panel 1 proposed to report on potential power outputs and costs. As such information had to come from the manufacturers themselves, to avoid any possibility of antitrust action, all requests for information were channeled through the Federal Communications Commission. The manufacturer supplied the information to the FCC where it was digested. The composite data was then forwarded to TASO with all identification of the manufacturers removed. However, the data had such wide cost variations that it was considered inconclusive and was deleted from the Panel Report.

Considerable technical information was made available to Panel 1 through the fine cooperation of the FCC. This included information from its Mobile Monitoring Service on frequency stability, maintenance of power output, modulation characteristics, compliance with FCC rules and required maintenance time.

INITIAL COSTS—TRANSMITTER SELLING PRICES

Fig. 1 is a plot showing the average selling prices of VHF and UHF transmitters as obtained from the manu-

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* Original manuscript received by the IRE, February 24, 1960.

† General Electric Co., Syracuse, N. Y.
‡ Radio Corp. of America, Camden, N. J.

[1] "Engineering Aspects of Television Allocations," TASO Rept.; March 16, 1959.

facturers. The connecting lines have been drawn between the values merely to better indicate the trend between VHF and UHF. However, it should be noted that transmitters are usually available for only the rated powers as indicated by the points themselves, and the intermediate powers would not necessarily be available at the prices indicated by the graph. It would normally be necessary, if an intermediate power is required, to employ a transmitter of the next higher standard rating. The VHF selling price averages include both low channel and high channel facilities inasmuch as their differences were not great. The VHF prices all include one set of operating tubes. However, the UHF prices, except for powers of 1 kw and lower, do not include tubes so the UHF curve would actually be somewhat higher than indicated. The VHF prices for 20-kw and 35-kw ratings were reported together so this average was plotted at the intermediate 27½-kw rating. The UHF 20-kw and 25-kw prices were likewise averaged together at the 22½-kw rating.

Fig. 1 indicates that for a given transmitter peak power output, the UHF transmitter price is considerably greater than for VHF. However, it must be borne in mind that the higher effective radiated powers (ERP) at UHF are obtained largely through use of the higher gain antennas which are quite feasible at the higher frequencies. The result is that lower power transmitters are usually used at UHF than at VHF so the actual initial transmitter costs, at typical installations, are probably not greatly different.

The selling prices given in Fig. 1 were for transmitters designed for the normal 2/1 ratio of visual power/aural power. For use in discussions regarding possible higher ratios, it was estimated that if a VHF transmitter were specifically designed for a 4/1 ratio it would have a price about 15 per cent lower, and one designed for 10/1 ratio about 25 per cent lower, than the values of Fig. 1. The corresponding reductions for UHF were estimated at about 10 per cent and 20 per cent.

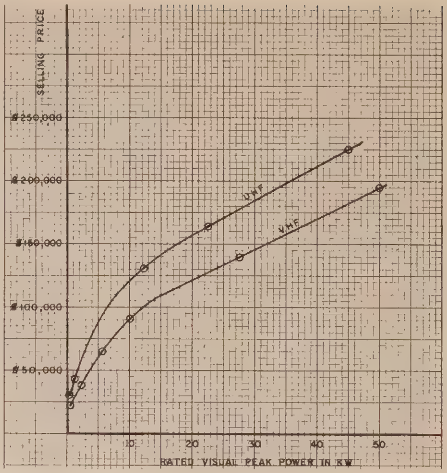

Fig. 1—Comparison of selling prices of VHF and UHF TV transmitters (January, 1958).

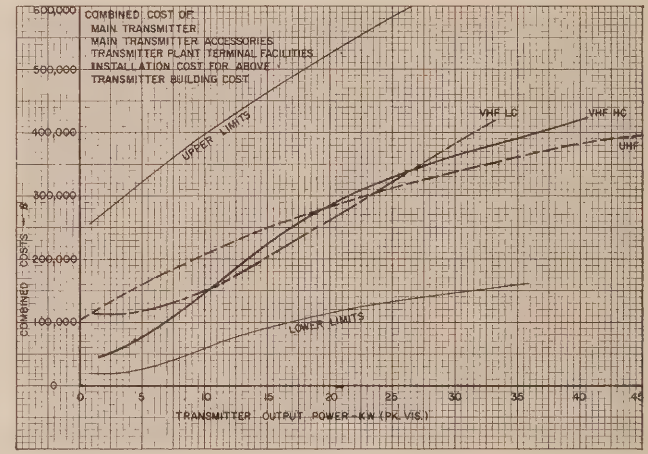

Fig. 2—TV transmitting plant costs.

Transmitting Plant Costs

The "transmitting plant costs" were obtained from the questionnaires to the broadcasters. It should be noted that the term "transmitting plant" as used above includes the main transmitter, the main transmitter accessories, and the transmitter plant terminal facilities, plus installation and transmitter building costs.

The data which came back had tremendous spreads in their values. Some installations must have been very plush indeed, and others equally austere! A method of presentation was arrived at, however, which produced a meaningful display. The data were grouped, for each band, into five groups of visual transmitter peak powers. For the VHF low channels the groupings were from 0 to 2 kw inclusive, 2 to 6 kw, 6 to 12 kw, 12 to 25 kw, and over 25 kw to 35 kw inclusive. For the VHF high channels the groupings were from 0 to 2 kw inclusive, 2 to 6 kw, 6 to 12 kw, 12 to 20 kw, and over 20 kw to 50 kw inclusive. For UHF the groupings were 1 kw, 5 kw, 12.5 kw, 25 kw, 45 kw. In the TASO Report complete charts are included for each band showing the maximum, minimum, and the average costs reported for each grouping, and the numbers of stations whose data were included.

Fig. 2 shows the curves obtained by joining, for each band, the average cost points of each grouping to show the comparison between VHF and UHF. The upper and lower limits are shown to indicate the magnitude of spread of the original data. From Fig. 2 it is seen that, comparing the average costs of low channel VHF and high channel VHF, no significant difference was found for transmitter power outputs of 7.5 kw and higher. The average cost of a high power UHF transmitting plant (say 25 kw and above) was found to be a little less than that of the average VHF plant. At lower powers, however, the UHF plant averaged substantially higher in cost than VHF plants.

Considering the spread of the initial data itself, we can see that the differences in transmitting plant costs between the three bands are not great.

Antenna Plant Costs

Information on the selling prices of antennas for the various power ratings and gains was obtained from three manufacturers. Antennas were listed only for the standard power gains (1, 2, 3, 4, 5, 6, 8, 10 etc.); however, the values were connected together as a curve to highlight the relations between VHF and UHF prices. A fairly linear relation was noted between selling price and power gain as indicated in Fig. 3. These graphs show the average selling prices (but for standard ratings only) for low channel VHF, for high channel VHF, and for UHF. For a given gain, the VHF high channel antennas are less costly than are the VHF low channel units, and for UHF antennas are much less costly than for VHF. However, again, it should be pointed out that higher gain antennas are normally used at UHF than at VHF, and for VHF high channel than for VHF low channel, so the typical antennas that might be used would probably not differ greatly in price.

Comparison of Antenna Plant Costs

A more meaningful comparison is the one of typical antenna plant costs which includes not only the cost of the antenna but also the costs of the diplexer, transmission line, tower and erection. These data were obtained from the questionnaires to the stations.

The data had very great spreads of costs as reference to the complete TASO report will show. After some experimentation in plotting the information it was found that, due to the predominant effect of the tower height, costs vs tower height produced a meaningful display. To avoid confusion the VHF low channel information was limited to stations operating at 100-kw ERP, and VHF high channel to stations operating at 316 kw. Due to the smaller number of returns, all UHF data was included.

Fig. 4 shows average curves only taken from the TASO report. To indicate the spread of the original data, approximate lower and upper limits are indicated. It is seen that the average curves are fairly linear—at least out to about 1000-foot tower height. The differences of antenna plant costs for the three bands are not great—although the UHF antenna costs tend to average somewhat less than those for VHF.

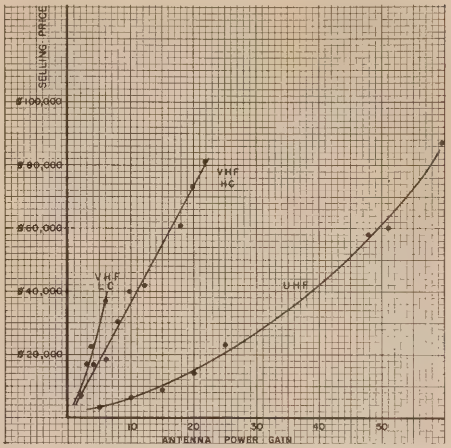

Fig. 3—Average selling prices of TV transmitting antennas (January, 1958).

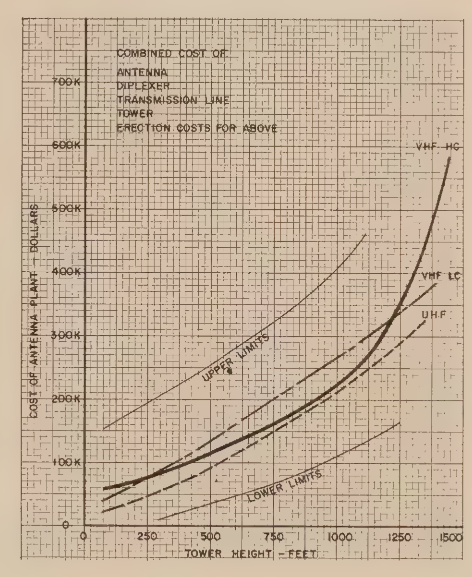

Fig. 4—Average antenna plant costs.

Total Cost of Transmitting Plant

The total cost of a transmitting plant includes the costs of the transmitting plant and the antenna plant. Because of the various manners in which transmitter, accessories, antennas, transmission lines, towers, etc. are combined in different stations, it was not felt correct to merely add the data of Fig. 2 (as obtained by one committee) to the data of Fig. 4 (as obtained by another committee). Rather, the information on the total cost of the transmitting plant was solicited directly from the stations.

Again, the spread of received data was very great and again the predominant effect of the tower height was evident. In Fig. 5 the averages of the TASO Report data are plotted to show the trends between the three bands. On the average, maximum power VHF high channel stations seem to cost about 25 per cent more than maximum power low channel VHF stations. UHF stations operating at powers up through 300-kw ERP seem to cost about 10 per cent less than the VHF low channel stations. Little information was obtained regarding 500- and 1000-kw ERP UHF stations, but it appeared that their costs were comparable to those of maximum power VHF low channel stations.

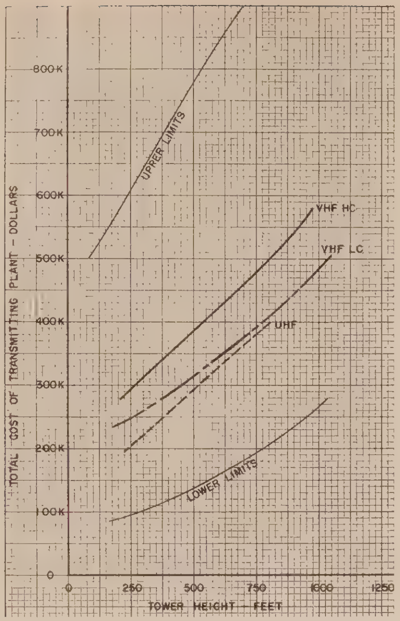

Fig. 5—Average total cost of transmitting plant.

Monthly Operating Costs

Values of the power input figures and estimated operating tube costs per hour were received from the transmitter manufacturers, and these are included in the full TASO report. They indicate that a UHF transmitter consumes more primary power, for a given peak power output, than does a VHF transmitter, and for a given peak power output the tube cost per hour is greater for UHF. Some savings in both areas would result from a higher ratio of visual/aural power.

For more meaningful information on the monthly operating costs, the data received back from the broadcasters was analyzed, and this is summarized in Fig. 6. These monthly operating costs include only primary power costs, tube costs, and maintenance parts. All figures were normalized to a common base of 455 hours per month of operation.

The data were assembled, for each band, into groups by visual transmitter peak powers. For VHF low channels the groupings were from 0 to 2 kw inclusive, 2 to 6 kw, 6 to 12 kw, 12 to 25 kw, and over 25 to 35 kw inclusive. For VHF high channels the groupings were 0 to 2 kw inclusive, 2 to 6 kw, 6 to 12 kw, 12 to 20 kw, and over 20 to 50 kw inclusive. For UHF, the groupings were 1 kw, 12.5 kw, 25 kw, 45 kw. In the TASO Report complete charts are included for each band showing maximum, minimum and average operating costs as reported for each grouping, as well as the number of stations for which data is included.

Fig. 6 shows the curves produced by joining, for each band, the average operating costs points of each grouping to indicate the trend between VHF and UHF. The upper and lower limits indicate the amount of spread in the original data. These curves show that, for a given power output, the average operating costs for high channel VHF stations average about 15 per cent higher than those of low channel VHF stations. For UHF stations the operating costs varied from about 20 per cent higher than for low channel VHF stations for the lowest powers to 100 per cent higher for transmitter power outputs above 15 kw.

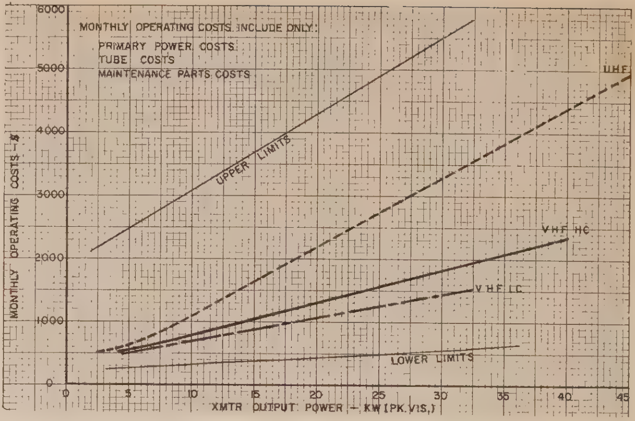

Fig. 6—Monthly operating costs.

However, if we consider that lower power transmitters are more often used at UHF than at VHF (because of the use of the higher gain antennas) it is probable that the differences in operating costs at typical installations are not very great.

Reliability

For information on characteristics of television broadcast stations which, taken together, measure reliability, the committee turned to the files of the FCC. The characteristics deemed important, and the variation between VHF and UHF follow:

1) Frequency stability—Reports of off-frequency operation, both of the visual transmitter and the intercarrier difference between visual and sound, occurred in more than half the UHF stations sampled, while the number of high VHF and low VHF channel stations off frequency was less than twenty per cent and ten per cent, respectively, of those sampled. This variation results at least partly from the greater use of outside frequency measuring services by the VHF stations—in over 90 per cent of the stations sampled compared to 51.2 per cent of the UHF stations. There appeared to be a general lack of frequency measuring service available to UHF stations due to the shorter transmission range of UHF stations and the lack of UHF measuring equipment.
2) Modulation characteristics—The VHF visual transmitters were generally better than UHF units, particularly with respect to linearity. This is believed to be at least partly due to a tendency to continue to operate tubes to the point of degradation of output at UHF to minimize operating cost.

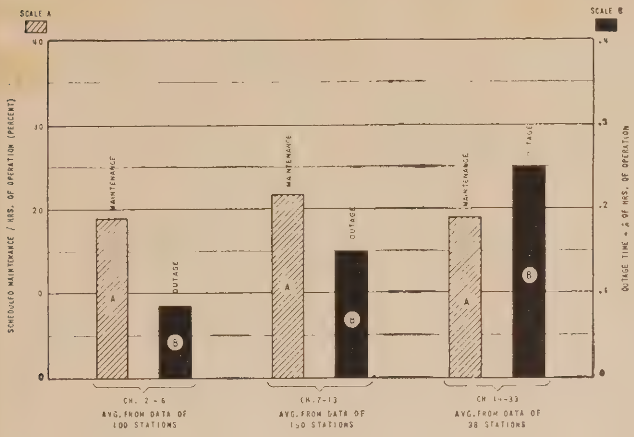

Fig. 7—Comparison of transmitter maintenance and outage time.

3) Maintenance and outage time—Fig. 7 compares low VHF, high VHF and UHF stations. Outage time, although relatively low for all three groups of stations, is clearly greatest for the UHF group despite comparable maintenance effort.
4) Tube life—Tube life at UHF was found to be generally shorter than VHF. This was reflected in the higher operating cost per hour on UHF.
5) Avenues of needed improvement—There are two general areas where the committee found improvement needed under present FCC standards. The first, improvement in tube life, was mainly a problem at UHF. The second, improved frequency stability and measurement, was needed to a degree in all three bands, most at UHF, least in the low VHF band. Table I shows the visual carrier frequency stability required. The first column shows the present FCC standard; the second, that needed if precise frequency control is to be used to reduce co-channel interference; and the third, the still greater stability needed for very precise frequency control to achieve maximum reduction of co-channel interference.

Table II shows the possible accuracy of frequency monitoring by several different methods.

It will be noted that WWV transmissions may be used to check the frequency of low VHF stations operating under the precise standards. For very precise frequency stability at low and high band VHF, and precise stability at UHF the atomic resonance standard is adequate. Even this is hardly sufficient to achieve the needed stability for very precise operation at UHF. Fortunately, the large number of channels available in the UHF band makes the need for very precise stability unlikely.

In addition to the more complicated monitoring means required for improvement in frequency stability, the frequency control used to drive the transmitter must also be improved if the need for continual checking against the standard is to be avoided.

TABLE I

REQUIRED VISUAL CARRIER FREQUENCY STABILITY[2]

	FCC	Precise	Very Precise
Low VHF	±1000 cycles	5 parts in 10^8	1 part in 10^8
High VHF	±1000 cycles	2 parts in 10^8	4 parts in 10^9
UHF	±1000 cycles	5 parts in 10^9	1 part in 10^9

TABLE II

MEANS OF FREQUENCY MEASUREMENT

Present TV frequency monitors ±500 cycles[3]	(±5 parts in 10^7)
Monitoring by use of WWV transmissions	5 parts in 10^8
Monitoring by use of VLF transmissions (not presently available)	2 parts in 10^9
Monitoring by use of atomic resonance standard	1 part in 10^9

ANTENNAS

In addition to the cost studies discussed earlier in this paper, the Committee on Television Antennas gathered information on transmission lines and towers. Its chairman also chaired the Task Group on Directional Antenna Tests. Out of the work of this group grew the directional antenna tests reported in another paper. A summary of information obtained on transmission lines and towers follows:

Transmission Lines

To develop cost data on the transmission lines used at UHF and VHF, the committee laid out typical 1000-foot runs of co-axial transmission lines, and waveguides including elbows, gas barriers, etc. This information is summarized in Fig. 8.

Towers

The effect of height of the supporting tower on cost was developed from cost data solicited from a number of manufacturers. The relation between cost and height is shown in Fig. 9. Insufficient data were received for tower heights between 1250 and 1600 feet, but they have been included in the dashed portion of the curve. A medium-sized antenna was assumed in these calculations. The effect of size of the antenna on the cost of a 1000-foot, 50 pound per square inch tower is shown in Fig. 10, and the effect of variation in design wind pressure is shown in Fig. 11.

Of these parameters, only the antenna size affects the relative cost of UHF and VHF installations. Because of the higher effective radiated power required at UHF an antenna having a higher wind load is required. The increase is modest however, amounting to an average of perhaps 15 per cent.

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[2] *Ibid.*, see Sect. 24.4.3.

[3] Includes check against a standard frequency or measuring service at intervals varying from a few months at low VHF to a few weeks at UHF.

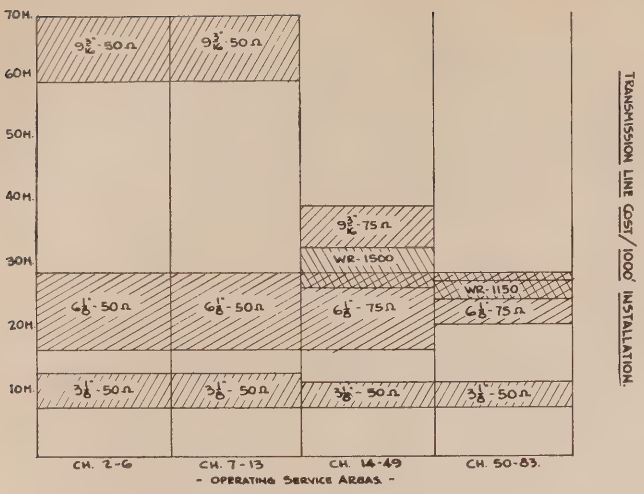
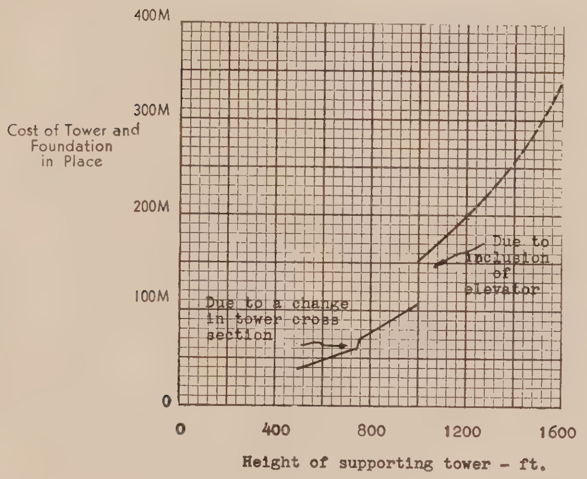


Fig. 8—Equipment cost information.



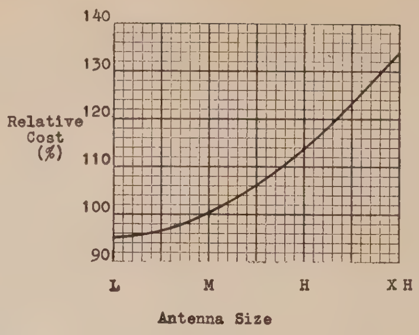
Specification: EIA Standard TR-116
Wind Pressure: 40 lbs/sq. ft. for under 1000 ft.
50 lbs/sq. ft. for over 1000 ft.
Antenna: Med. size (100 sq. ft. project area at 50 ft.)
Transmission line: 12 in. total width
Elevator: In towers over 1000 ft.
All towers guyed.
Cost does not include antenna or transmission line.

Fig. 9—Cost of tower vs height.

Data on permissible deflection of antennas under the action of wind were solicited from several manufacturers. A tabulation of these angles for wind pressure of 10 pounds per square foot, for various types of antennas, is included in the committee report. These data may be summarized here by stating that a well designed guyed tower should have a maximum deflection of 0.17 degrees at a wind pressure of 10 pounds per square foot at the base of the antenna.

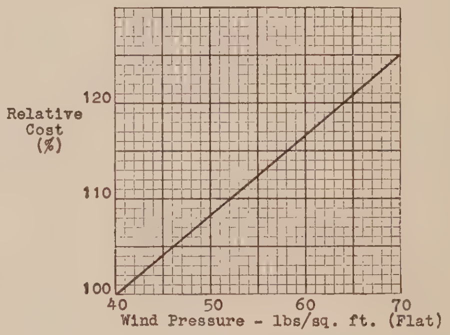
REPEATER TRANSMITTERS

The committee found need for definitions of the several terms used to define satellites, translators and boosters. Table III (opposite) was, therefore, prepared.



L—4-bay superturnstile Ch. 4–6
6-bay superturnstile Ch. 7–13
2-bay slotted ring
M—6-bay superturnstile Ch. 2–6
12-bay superturnstile Ch. 7–13
3–5-bay slotted ring
3-bay helical high band
H—12-bay superturnstile Ch. 4–6
high gain UHF—slotted cylinder,
helical, high gain
XH—12-bay superturnstile Ch. 2–3
Tower—1000 ft. high, 50 lbs/sq. ft. design

Fig. 10—Relative cost of tower vs antenna size.



Specification

Tower: 1000 feet high
No elevator
Transmission Line 12 in. total width per ft. of height
Antenna: Medium size (100 sq. ft. project area at 50 feet)

Fig. 11—Relative cost of tower vs wind pressure.

The generic term "repeater" was selected as being applicable to all three classes of nonoriginating stations.

General Repeater Performance

The committee, in its report, found that generally satisfactory reception of television translators had been reported. In fact, it was noted that they were operating with aural power levels at least 6 db below the peak visual power, and that a number of translators were known to be operating with aural power 10 db below the standard ratio. In view of this history the committee recommended that the ratio of visual to aural power be changed from the present standard of 2:1 to 4:1.

UHF Booster Tests

A series of measurements and observations were outlined by the committee for the UHF booster already in operation at Waterbury, Conn. Much of this work

TABLE III

DESCRIPTION OF VARIOUS TYPES OF TELEVISION BROADCAST STATIONS

	Standard	Satellite	Translator	Booster
1. Presently provided for in rules	x	x	x	(a) (b)
2. Limited by rules to UHF broadcast channel only			x	(a)
3. UHF and VHF channels	x	x	(b)	(b)
4. Cannot originate programs			x	x
5. Does not ordinarily originate programs		x		
6. Can originate programs	x	x		
7. Must repeat program on same channel				x
8. Must repeat program on another channel			x	
9. Programmed only by off-air pickup			x	x
10. Programmed by line relay or off-air pickup	x	x		
11. Maintains standard mileage separations	x	x	x_1	
12. Licensed on non-interference basis			x(a)	(a) (b)
13. Maximum power limited by technical factors				x
14. Maximum ERP/height limited by rules	x	x		(a)
15. Remote control operation now permitted			x	(a) (b)
16. Maximum transmitter power limited by rules	x	x	x(c)	(a) (b)
17. Unlimited directional antenna permitted by rules			x	(a) (b)

x_1 = With respect to regular and satellite stations only.
(a) = Presently proposed in Docket No. 11331 ("On Channel" Booster Stations—UHF only).
(b) = Presently proposed in Docket No. 12116 (Low Power Repeater Stations).
(c) = Presently limited to 10 watts by rules but increase to 100 watts proposed in Docket No. 12567, and approved for adoption by the FCC effective December 26, 1958.

could not be completed in time to be included in the TASO report.

The following two paragraphs are quoted from the tentative conclusions of the interim report on the Waterbury tests:

> Thus far it is indicated that there are locations where interference between main station and repeater station cannot be reduced by simple antenna orientation techniques. Further investigation is required, particularly in the use of such methods as cross-polarization to obtain a better discrimination of wanted to unwanted signals. It is planned to conduct tests using two matched re-transmitting antennas at the output of the repeater. One will be mounted for horizontal polarization and the other for vertical.
>
> The only assuring procedure so far for discriminating against an undesired signal in favor of the desired signal for ghost elimination, where both signals are arriving at the receiver test sight at small angles, is the use of low elevations (a few feet above the ground) to reduce or eliminate the signal from the unwanted source. Shielding one signal with a car or house has also shown some promise. This technique will also be investigated further.

Survey of UHF Translators

A task force of the committee surveyed translator licensees and television stations being rebroadcast, by questionnaire. Data thus obtained were compared with information in FCC files. Table IV presents some of the results.

Much significant data were obtained which cannot be reproduced here for lack of space.[4]

TABLE IV

	TASO Data[5]	TASO and FCC Data[5]
No. of areas served by TV translators	41	92
No. of individual communities	65	132
No. of individual TV translators authorized	60	156
No. of areas using 1 translator	25	53
No. of areas using 2 translators	12	23
No. of areas using 3 translators	4	15
No. of areas using more than 3 translators	—	1
Total population in areas served by translators	321,150	717,893
Total no. of homes in areas served	83,896	187,500[6]
Total no. of UHF receivers in use	37,641	84,500[6]
Per cent of homes equipped for UHF reception	45%	45%[6]
Total investment in translator installations	$375,655	$892,764
Average cost of a 1-channel system	$ 6,212	$ 5,380
Average cost of a 2-channel system	$ 13,040	$ 11,977
Average cost of a 3-channel system	$ 20,764	$ 18,820
Cost of one 5-channel system	—	$ 60,681[7]
No. of installations costing less than $4,000 per channel	3	13
No. of installations costing $4,000–$6,000 per channel	21	49
No. of installations costing $6,000–$8,000 per channel	7	15
No. of installations costing $8,000–$10,000 per channel	6	9
No. of installations costing over $10,000 per channel	3	5
Annual operating cost of all translators	$ 52,638	$162,661
Average annual operating cost of 1-channel system	$ 1,161	$ 1,149
Average annual operating cost of 2-channel system	$ 1,990	$ 3,140
Average annual operating cost of 3-channel system	$ 2,210	$ 2,720
No. supported by public funds		14
No. supported by private funds		8
No. supported by TV broadcast stations		5
No. supported by public subscription		66
Average ERP employed		189 watts
Average height of antenna above community		1,515 feet
Average maximum distance served	22 miles	

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[4] *Op. cit.*, "Engineering Aspects of Television Allocations," The interested reader is referred to Sec. 1.2.6 in which all of the information is included.

[5] See text for explanation

[6] Extrapolated.

[7] Unusual installation employing a high tower.

Determining the Operational Patterns of Directional TV Antennas*

F. G. KEAR†, FELLOW, IRE, AND S. W. KERSHNER‡, MEMBER, IRE

Summary—In January, 1959, the Television Allocations Study Organization authorized its Committee on Directional Antennas to conduct field tests on directional TV antennas looking toward development of a means whereby the operational antenna pattern could be determined and to explore the effect of reflections and anomalous propagation on the degree of directivity actually obtained as compared with that calculated.

Tests were subsequently carried out at WBZ-TV in Boston, Massachusetts, and at WKY-TV in Oklahoma City, Oklahoma, with special directional antenna systems possessing various degrees of directivity. Measurements were made at distances varying from a few miles from the transmitter to well over 100 miles from the transmitter. Within the limits imposed upon the tests by the choice of sites, nature of the terrain, and a limited period of observation, it was found that propagation conditions did not materially affect the directivity of the array, even at distances where the scatter fields were of appreciable magnitude.

In the course of these measurements and tests, a procedure was developed whereby the operational antenna pattern could not only be determined, but also rechecked at suitable intervals thereafter.

INTRODUCTION

IN THE field of television broadcasting, vertical directivity of the transmitting antenna system has long been employed in order to make the most efficient use of the available radiated power. However, with few exceptions, directivity in the horizontal plane has been avoided. Two of the factors behind this reluctance to use directional antennas for TV were: 1) the absence of a tested and acceptable procedure for proving the performance of a TV antenna pattern and for making subsequent checks on it, and 2) uncertainty as to the extent to which the directivity could be maintained in the suppression area under conditions of serious local reflections or tropospheric scatter.

In its study of the over-all problems of television allocations, it became evident to the members of TASO that antennas with horizontal directivity would be useful in allocation if dependence could be placed upon their performance. It was apparent that, in the limited time available to TASO, it would be impossible to make an exhaustive study of all of the factors affecting the performance of directional antennas under all combinations of local and distant terrain conditions. However, it was agreed that even a limited amount of information would be valuable, and a special group was appointed to review the problem and make recommendations as to the best possible procedure.

This initial study led to the formation of a "Committee on Directional Antenna Tests," which was charged with preparing a program of tests on directional antennas, the results of which may be expected:

> First, to form the basis for establishing procedures for determining the extent to which the operational antenna pattern corresponds (1) with the antenna pattern as measured at the antenna test site, and (2) with the antenna pattern previously calculated or otherwise determined to be required for the site in question.
>
> Second, to provide corroborative detail on the extent to which the behavior of the distant field (100 km or more) from a TV directional antenna is determined by the directivity of the operational antenna pattern.

During this same period the Association of Maximum Service Telecasters had independently decided to conduct tests on directional TV antennas, and upon the formation of the Directional Antenna Committee the tests which AMST had proposed were made a part of the TASO program.

The Westinghouse Broadcasting Company, Inc., indicated their willingness to make the facilities of television station WBZ-TV available for some of these tests and the licensee of WKY-TV in Oklahoma City also agreed to cooperate in the project. WJMR-TV in New Orleans offered the use of their experimental operation on Channel 12, but the experimental authorization was terminated prior to initiation of the tests.

WBZ-TV possessed a unique advantage in that it employed separate antennas for visual and aural transmission. This meant that the aural pattern could be directionalized to some extent without seriously affecting the over-all television service rendered by the station. It provided maximum power-height (FCC Zone I) so that observations could be conducted over substantial distances in order to observe the effect of diffraction and scatter.

WKY-TV was a valuable acquisition since the station had proposed to purchase a new antenna for emergency use and now agreed that it could be modified to permit rotation while installed. An additional calibrating or reference antenna could also be added to this structure and the over-all performance of the combination could be measured carefully on the test range before delivery to WKY-TV. Measurements made at the site after installation of the antenna would therefore permit comparison between the antenna patterns measured at the test range and the performance after erection at the transmitter site.

The program of tests finally proposed by the Committee was approved by the appropriate body of TASO and

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* Original manuscript received by the IRE, February 15, 1960.

† Kear and Kennedy, Washington, D. C.
‡ A. D. Ring and Associates, Washington, D. C.

funds for the test program were allocated. The tests at WBZ-TV were made during the early part of 1959, terminating in time to move the measuring equipment and personnel to Oklahoma City for the tests at WKY-TV. These tests were conducted during the fall of 1959 and were concluded in December of that year. A description of the tests and the results obtained follow.

MEASUREMENT OF THE PERFORMANCE OF THE ANTENNA AT TELEVISION STATION WBZ-TV

The antenna installation for WBZ-TV consists of two three-section superturnstile antennas mounted one above the other on a 1107-foot tower which is located approximately eight miles southwest of Boston, Massachusetts. For the purposes of this test the upper antenna was used as an experimental directional antenna for aural transmissions on 71.74 mc.

Separate transmission lines were installed to connect the north-south and east-west superturnstile elements to a special power dividing network installed in the transmitter building. This network was designed to provide either "nondirectional" operation with normal 50-50 power division or directional operation with a power ratio of 20 db between the two sets of superturnstile elements. For both modes of operation the normal 90° phase relationship was maintained. The high power elements were oriented at a true bearing of approximately 351.5° and this was the expected direction of minimum radiation from the directional antenna. During the period of the field measurements, the power dividing network was switched to provide alternate 15-minute periods of nondirectional and directional operation with the same power input from the aural transmitter. Fig. 1 shows the expected radiation patterns in terms of relative voltage based on pattern shapes for single superturnstile elements supplied by RCA.

The field measuring program consisted of obtaining three types of measurements. Fig. 2 is a map showing the expected direction of minimum signal and the locations at which the field measurements were obtained. The first type of measurements comprised field strength measurements for both directional and nondirectional operation made along four radial routes from the transmitter, at distances ranging from 9.0 to 50.4 miles. At each measuring location, a continuous mobile recording of the signal was made over a distance of approximately 100 feet. These measurements were made with a half-wave dipole receiving antenna mounted 30 feet above the road surface. At each location, recordings were obtained over the same path for both directional and nondirectional operation during adjacent 15-minute periods.

The second type of measurements consisted of field strength measurements made at locations traversing a "cross minimum" route at distances ranging from 18.6 to 21.8 miles. These measurements were made in the same manner as described above for the radial field strength measurements.

The third type of measurements consisted of time recordings of signal strengths at several fixed locations over periods ranging from 7 to 18 days. At each location, the signal was recorded for alternating 15-minute periods of nondirectional and directional operation.

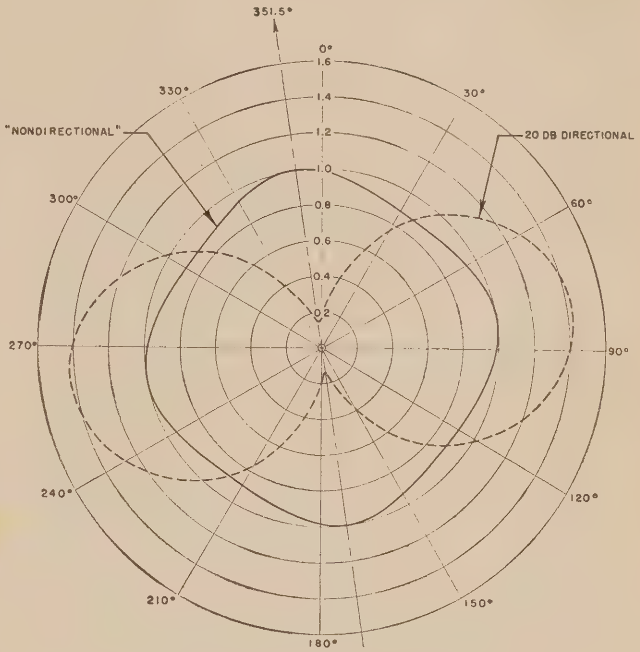


Fig. 1—Computed horizontal radiation patterns of WBZ-TV antenna.

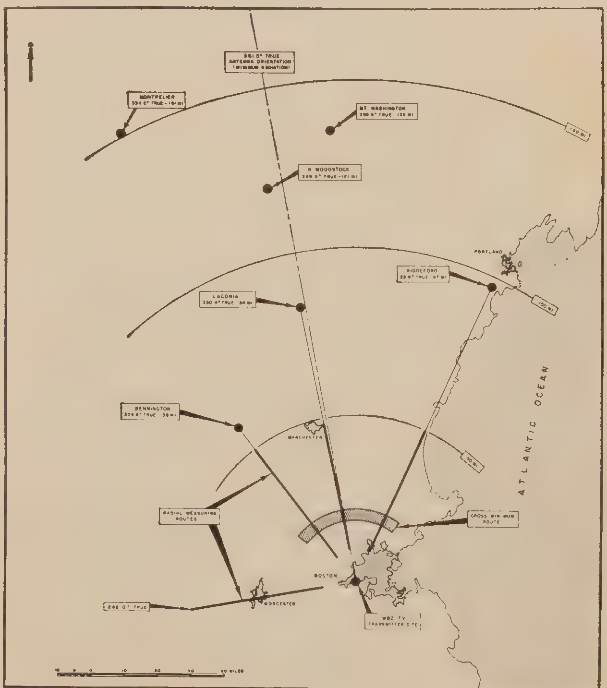


Fig. 2—Map showing WBZ-TV transmitter site and measuring locations.

Fig. 3 shows the results of the measurements made along the four radial paths from the transmitter. For each location the median signal levels were determined from the recorder charts for directional and nondirectional measurements along the same path. The ratio of these median values expressed in db is plotted vs distance from the transmitter station. The average ratio and the standard deviation for each direction are indicated on the graphs. The standard deviation was less than 0.8 db for all four radial directions.

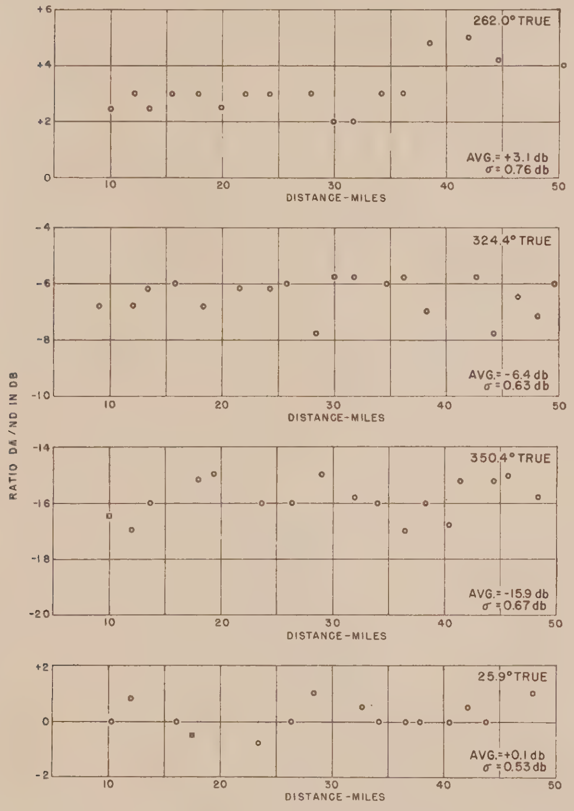


Fig. 3—Radial ratio measurements, WBZ-TV.

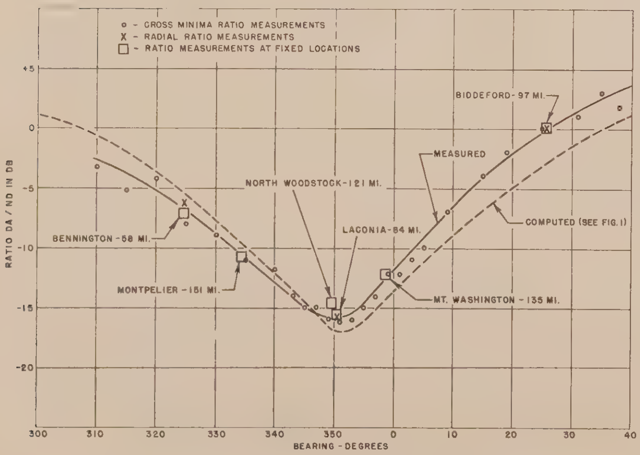


Fig. 4—Measured and computed ratios, WBZ-TV.

Fig. 4 shows the ratios obtained from the cross minimum measurements along with the average ratios obtained from the radial measurements and the average ratios obtained at the six fixed measuring points. The solid curve shows the average of the measured data, and the dashed curve shows the expected ratio based on the computed antenna patterns of Fig. 1. It should be noted that the expected ratio (*DA/ND*) in the direction of minimum radiation is 17 db instead of 20 db because the maximum radiation from the directional antenna is 3 db greater than from the nondirectional antenna.

Table I summarizes the results of the measurements obtained at the six fixed locations where time recordings of the signals were made.

TABLE I

Summary of Results of Recordings Made at Fixed Measuring Locations

Location	Bearing	Distance, Mi.	Number of Recording Periods	Average Ratio *DA/ND*
Bennington, N. H.	324.4°	58	190	− 7.1 db
Montpelier, Vt.	334.2	151	27	−10.9
North Woodstock, N. H.	349.5	121	35	−14.7
Laconia, N. H.	350.4	84	175	−15.5
Mt. Washington, N. H.	358.6	135	67	−12.4
Biddeford, Me.	25.9	97	185	+ 0.2

The number of periods for which 15-minute records of both nondirectional and directional signals were obtained is indicated for each location along with the average ratio of the signals. Comparison of the results as plotted in Fig. 4 shows close agreement between the ratios obtained at the fixed locations and the ratios obtained from the radial and cross minimum measurements made at closer locations. It should be noted, however, that the results obtained at 121 miles (349.5° true) indicate one or two db less suppression than the measurements made at closer locations. This effect may be due to scatter propagation modes which tend to "fill in" the minimum of the pattern.

With the exception of the Mt. Washington and Montpelier locations, the fixed locations were selected to represent typical rural receiving locations for the terrain involved. The Mt. Washington recordings were made at the site of television station WMTW-TV at an elevation of approximately 6300 feet above sea level. The Montpelier recordings were obtained at the Montpelier Community Television receiving site located on the southwest side of a mountain at an elevation of 1125 feet above sea level.

The equipment used at the fixed locations consisted of high-gain fringe-type antennas mounted at heights of 30 to 40 feet. Baluns and coaxial transmission lines were used to connect the antennas to crystal-controlled receivers which were connected to the recording meters. The receivers were calibrated on a daily basis with laboratory-type signal generators.

Figs. 5 and 6 show the distributions of the median signal levels for all 15-minute periods of nondirectional and directional operation recorded at the two fixed recording locations in the direction of maximum suppression. Smooth lines were drawn through the measured points, and the ratios of the signals exceeded for 50 per cent and 10 per cent of the time are indicated. These data do not indicate any consistent trend between the 50 per cent and the 10 per cent signal ratios.

MEASUREMENT OF THE PERFORMANCE OF THE ANTENNA AT TELEVISION STATION WKY-TV

An extensive program of measurements was undertaken to determine the performance of a special experimental directional antenna installed by television station WKY-TV at their transmitting site five miles north of Oklahoma City, Oklahoma. Careful control of the antenna design was possible because the management of station WKY-TV agreed to incorporate the directional antenna project into the installation of a new standby antenna system.

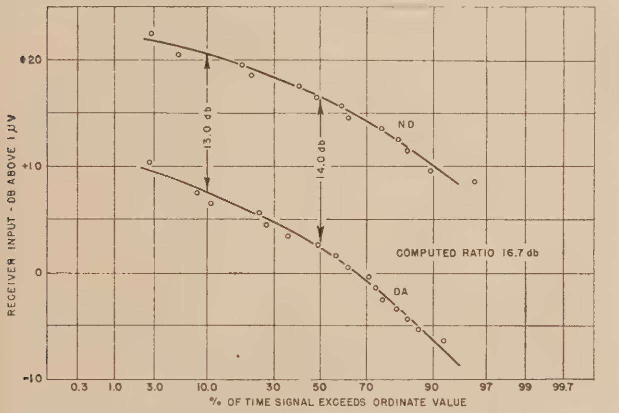


Fig. 5—Results of recordings made at North Woodstock, 349.5° true, 121 miles.

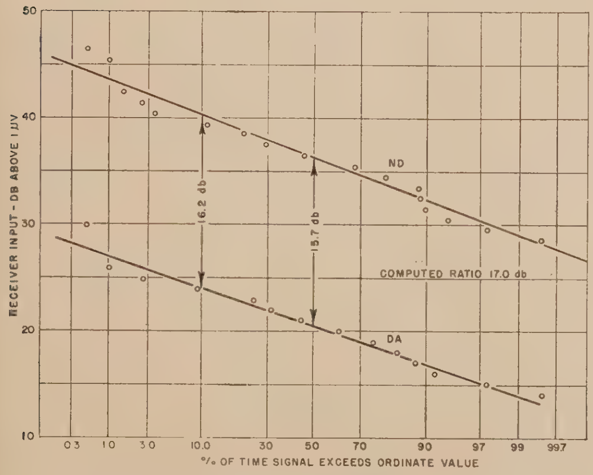


Fig. 6—Results of recordings made at Laconia, 350.4° true, 84 miles.

The directional antenna consisted of a modified RCA Type TF-3EM three-section superturnstile designed for operation on television Channel 4. Fig. 7 is a photograph showing the main antenna and the special reference antenna which is mounted some twenty feet above the upper superturnstile elements. The reference antenna consists of two folded half-wave dipoles mounted in the same horizontal plane with the spacing and phasing arranged to provide a "figure 8" type pattern and low coupling to the superturnstile antenna elements. Both the superturnstile antenna and the reference antenna

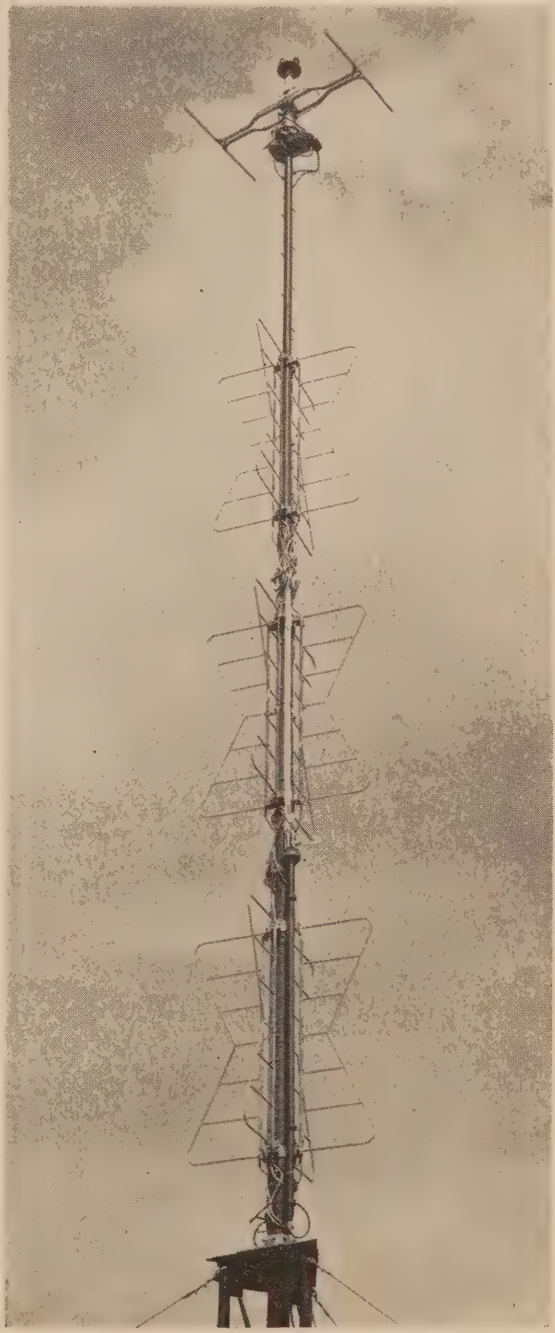


Fig. 7—Photograph of WKY-TV directional antenna system, showing main and reference antennas.

were equipped with motor drive mechanisms and remote control and bearing indicator systems so that the antennas could be independently positioned to any desired orientations. Flexible RG-117/U coaxial transmission lines provided connections between the antenna elements and the rigid $3\frac{1}{8}$-inch transmission lines used to connect the antennas to the transmitter. Three interchangeable power-dividing tees provided power ratios of 0, 10, or 20 db between the two sets of superturnstile elements. Motor-driven coaxial switches permitted switching the transmitter to either the superturnstile antenna or the reference antenna.

The special directional antenna and reference antenna were assembled by RCA and a complete set of pattern measurements was made at the Gibbsboro, New Jersey, test site of RCA. Fig. 8 shows measured horizontal patterns for the three modes of operation as made at Gibbsboro with the reference antenna removed. Similar pattern measurements were made at the aural carrier frequency, and pattern measurements were also made with the reference antenna in place. Analysis of these measurements showed that the reference antenna had only a small effect on the pattern of the main antenna.

The antenna was then shipped to Oklahoma City and installed on a 263-foot supporting tower located some 800 feet from the 969-foot main antenna tower of station WKY-TV. The field measurements made after installation included measurement of pertinent details of the radiation patterns at the visual carrier frequency, aural carrier frequency, and at sideband frequencies 2.0 and 3.6 mc above the visual carrier frequency. All measurements were made during the early morning experimental hours following sign-off of the regular WKY-TV program. Three basic types of measurements were made. The first type employed the reference antenna method for which measurements were made of the signals received from the main antenna and the reference antenna, with the reference antenna oriented for maximum signal at the measuring location. Measurements by the reference antenna method were made along four radial routes from the transmitter and along one cross minimum route, as shown by Fig. 9. These measurements were made with a half-wave dipole receiving antenna mounted at a height of 10 feet.

The second type of measurements utilized the rotation method. The signal received from the main antenna was observed as the main antenna was rotated. Measurements were made by this method at locations along the 90° radial route from the transmitter employing a receiving antenna height of 10 feet.

The third type of measurements consisted of recordings made for extended periods of time over two paths of 65 and 206 miles (see Fig. 9). Measurements were made on the visual carrier frequency at Bristow, Oklahoma, with the main antenna set at specific orientations for alternate 10-minute periods. Measurements were also made of the visual signal received from the KRLD-TV transmitter located near Dallas, Texas, with the WKY-TV directional antenna used as a receiving antenna.

The portion of the pattern providing minimum radiation (maximum suppression) was considered to be the most important area for exploration, and the "90° minimum" portion of the pattern (see Fig. 8) was selected for detailed study. The "0° maximum" was used as the reference for establishing suppression ratios.

Fig. 10 shows the results of the measurements of the 20-db pattern made by the reference antenna method along four radial routes. At each location, measurements were made of the signals from both the main antenna and the reference antenna at three cluster points spaced

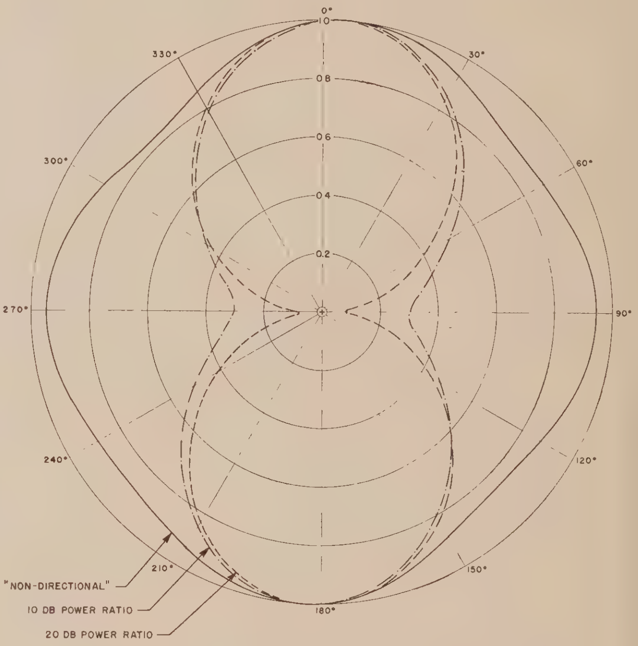


Fig. 8—Horizontal radiation patterns measured by RCA, 67.5 mc, reference antenna removed.

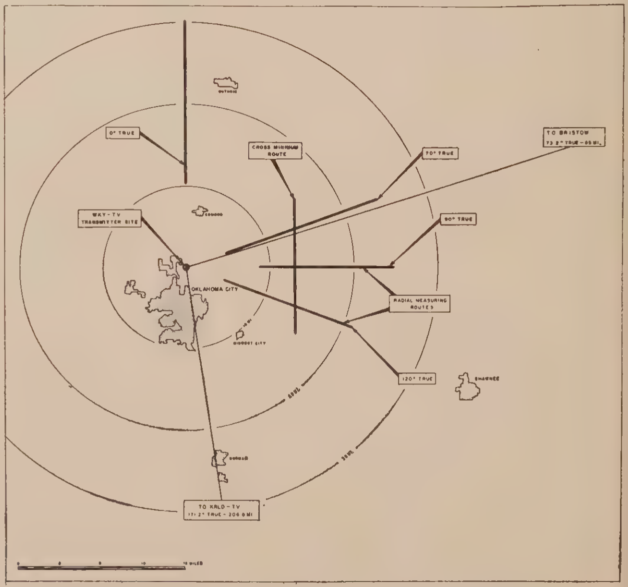


Fig. 9—Map showing WKY-TV transmitter site and measuring locations.

at 50-foot intervals along the road. The main antenna orientation remained fixed with the "north" elements aligned with true north, and the reference antenna was oriented for maximum received signal. The graphs show the minimum, average and maximum ratios for each measuring location.

Fig. 11 shows the results of the cross-minimum ratio measurements of the 20-db pattern made using the reference antenna method. Each point plotted on the graphs represents the ratio observed at a single measuring point along the cross-minimum route. The average results of the radial measurements are also shown.

Fig. 12 shows the results of measurements made at the aural and visual carrier frequencies and sideband frequencies using the point-by-point rotation method.

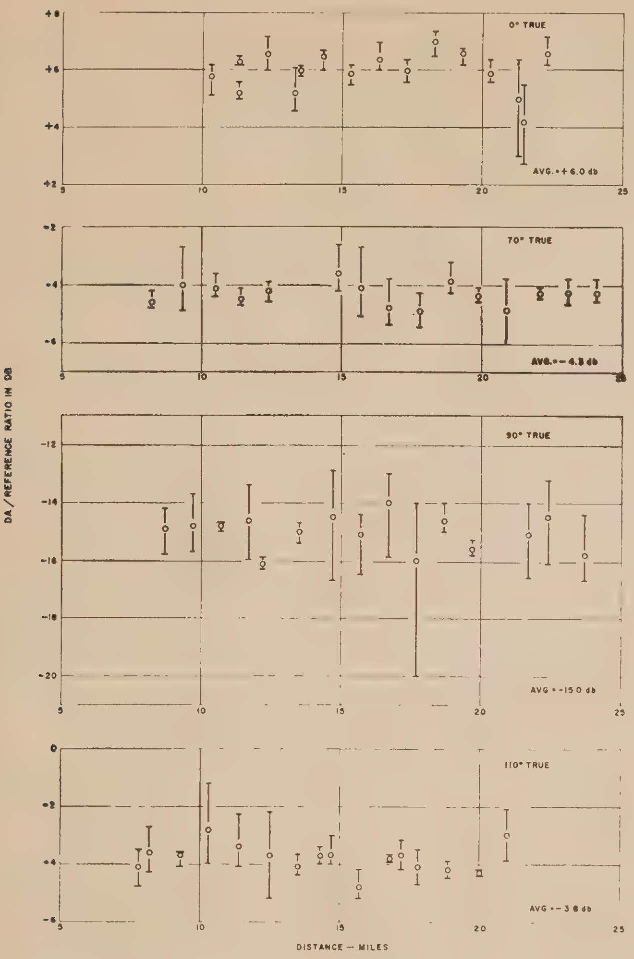


Fig. 10—Results of reference antenna ratio measurements made along radial routes, 20-db power ratio, visual carrier.

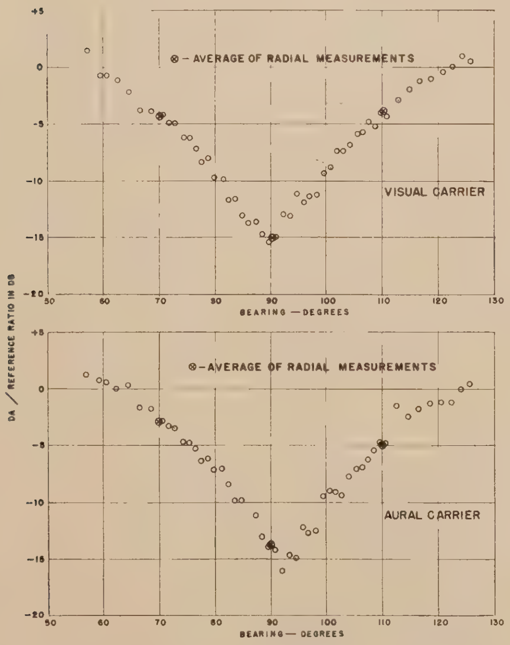


Fig. 11—Reference antenna ratio measurements along cross-minimum route, 20-db power ratio.

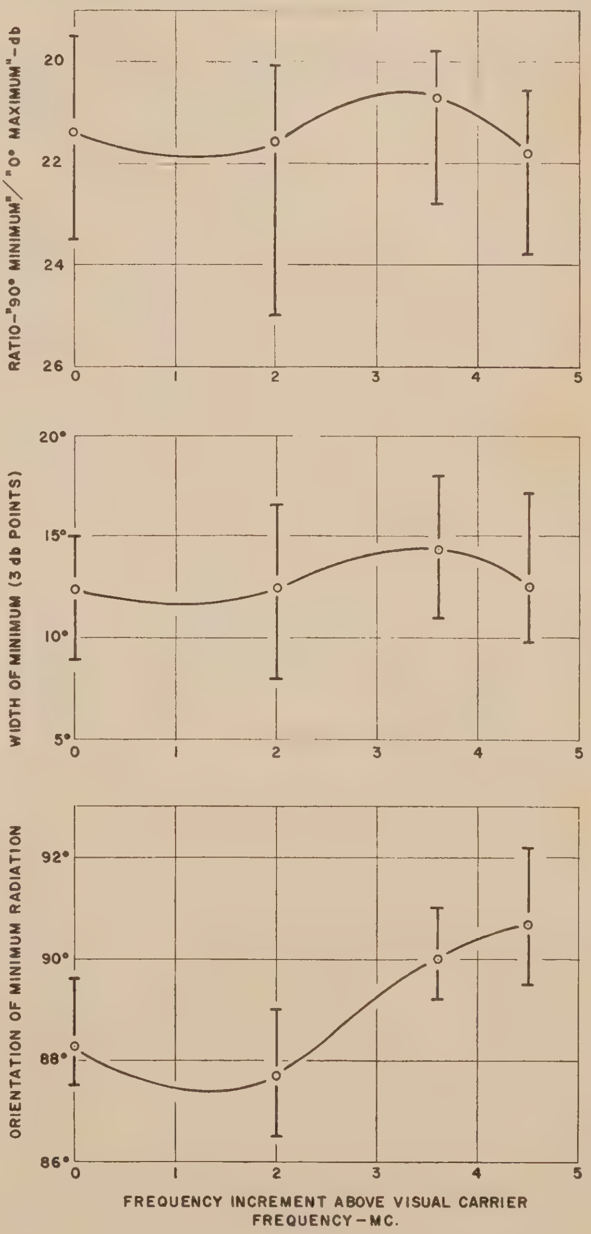


Fig. 12—Results of measurements made using point-by-point rotation method, 20-db power ratio.

Measurements were made at 17 locations along the 90° radial route, and the graphs of Fig. 12 show the minimum, average and maximum values observed. At each location, the received signal was measured as the antenna was rotated point-by-point over the sector required to provide details of the position and width of the 90° minimum of the radiation pattern. The signal obtained from the 0° maximum of the radiation pattern was also measured in order to obtain the ratio of minimum to maximum signal. Analysis of the data obtained by the rotation method indicates that the depth, orientation and width of the minimum of the radiation pattern vary as a function of both location and frequency. Substantial variations in the pattern parameters occurred at different locations in the same radial direction and even at locations spaced about 100 feet apart along the same road. These variations are believed to be caused by scattering of the signal caused by terrain irregularities. The test data indicate that the results of a large number of measurements made at different locations must be averaged to obtain an accurate operational radiation pattern.

Measurements of the 20-db pattern were made at Bristow during the early morning experimental hours for the period of October 7 through October 11, 1959. The measuring equipment was set up in a downtown hotel room and the signal was received by means of a fringe area type antenna mounted on the roof of the hotel. The visual signal was recorded for 30-minute periods, and the average results are given in Table II. During each period the signal was recorded both for the indicated orientation and with the 0° maximum towards Bristow, and the ratio of the median signals was established.

TABLE II

Results of Bristow Measurements
(73.2° True—65 Miles)

Orientation of Path Measured Clockwise from North Antenna Elements	Number of Recording Periods	Average Ratio of Signals Referred to 0° Maximum
80°	12	−16.6 db
90°	29	−20.6 db
100°	10	−14.4 db

Table III shows the results of measurements of the 20-db pattern made by employing the WKY-TV directional antenna as a receiving antenna to pick up visual signals transmitted by station KRLD-TV which operates in Dallas, on television Channel 4. The use of this reciprocal technique permitted obtaining data over a relatively long path (206 miles). The measurements were made between the hours of 1 A.M. and 5 A.M. from November 30 to December 12, 1959.

During the first ten minutes of each half-hour period the signal was recorded with the antenna oriented for maximum pickup from KRLD-TV (north superturnstile element towards KRLD-TV). During the next 10-minute period, the signal was recorded with the indicated orientation. The remaining time of each half-hour period was used to calibrate the receiving equipment and to record the noise level and any other signals present with the KRLD-TV transmitter shut down. The analysis of these periods of noise recordings showed the absence of significant signals arriving from other sources.

The median signal values (db above 1 μv at input to the receiver) for the ten-minute periods were determined and the average ratios for each day's recordings are given in Table III. The antenna orientations given are corrected for an error of 0.8° in the bearing indicator system which was discovered after the measurements were made.

TABLE III

Summary of Results, KRLD-TV Measurements

Date	Number of Periods	Average Ratio of Signals Referred to 0° Maximum		
		80.8°	90.8°	100.8°
Nov. 30	8		−19.9 db	
Dec. 2	8			−12.5 db
Dec. 3	8	−15.8 db		
Dec. 4	8		−19.8	
Dec. 5	8		−19.3	
Dec. 7	7		−22.7	
Dec. 9	8			−15.3
Dec. 10	8	−19.3		
Dec. 11	8		−22.2	
Dec. 12	4			−15.1
	4	−18.5		
Weighted Average		−17.7 db	−20.7 db	−14.1 db

Fig. 13 shows the results of the measurements of the 90° minimum portion of the 20-db radiation pattern by the several methods employed. Data are shown for operation at both the visual and aural carrier frequencies, and the dashed lines provide a comparison with the pattern measurements made before installation. The results show close agreement for the pattern measurements made after installation by different methods, and there is no great difference between the patterns measured before and after installation.

Fig. 14 shows the results of measurements of the 10-db directional antenna pattern before and after installation. Measurements of the 10-db pattern were not made at the two distant recording locations, but the measurements made by the reference antenna method and the rotation method are in close agreement.

Fig. 15 shows photographs of test patterns made at four locations between 4.9 and 6.7 miles from the transmitter with the 20-db antenna pattern employed. Fig. 15(a) shows the test pattern as received with the antenna oriented for maximum signal at the receiver. Figs. 15(b)–15(d) show the signals received with the antenna oriented for either minimum signal at the receiver or 10° from the position of minimum signal, as indicated. These photographs were selected as typical of test pattern observations made at locations in all eight

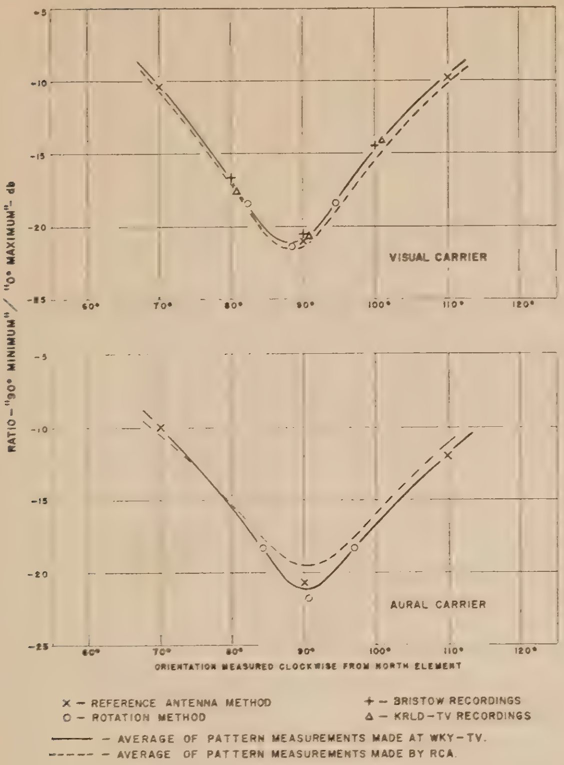


Fig. 13—Results of measurements of the 90° minimum portion of the pattern, 20-db power ratio.

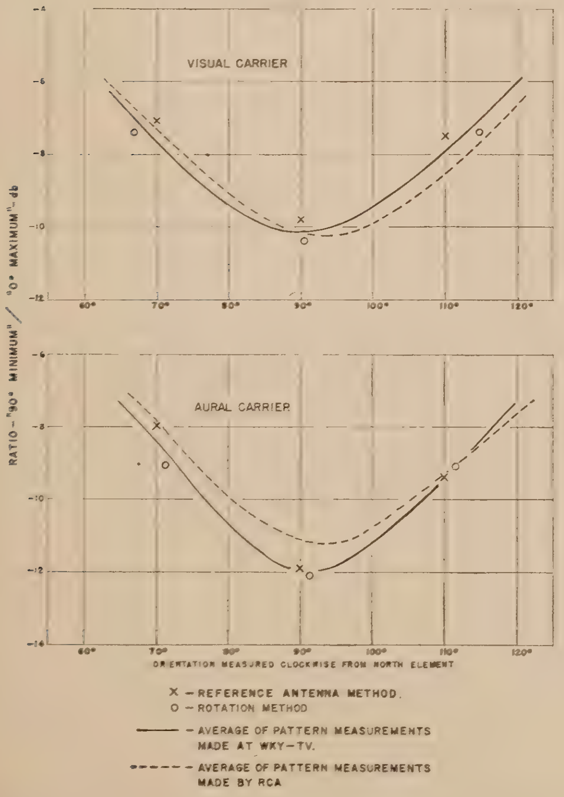
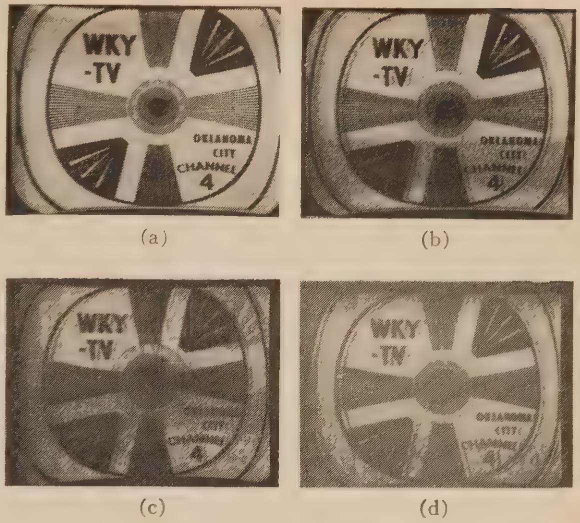


Fig. 14—Results of measurements of the 90° minimum portion of the pattern, 10-db power ratio.



(a) (b)

(c) (d)

Fig. 15—Photographs of test patterns, 20-db power ratio. (a) 6.2 miles west, antenna oriented for maximum signal. (b) 6.2 miles west, antenna oriented for minimum signal. (c) 5.8 miles southwest, antenna oriented for minimum signal. (d) 5.8 miles southwest, antenna oriented 10° from minimum.

directions from the transmitter. In all cases, ghosts ranging from moderate to severe were evident when the antenna was oriented for minimum received signal. In some cases, ghosts were still quite noticeable with the antenna oriented 10° from the minimum position. A limited number of test pattern observations made with the 10-db pattern indicated negligible to slight ghost problems in the directions of minimum radiation.

Recommended Method of Measuring the Operational Antenna Pattern of a Television Antenna

On the basis of the results obtained and described in this paper, it is considered that the most practical way of measuring the operational antenna pattern is the reference antenna method. The directional antenna should incorporate a rotatable reference antenna designed to operate on the visual, color subcarrier and aural frequencies. The coupling between the reference antenna and the main antenna or other nearby objects must be low enough to minimize errors due to radiation effects. The test transmitter may be of lower power than the transmitter normally used, but should have sufficient power to provide signals of adequate strength at the required measuring locations. The power into the antennas must be accurately determined and maintained. Controls should be available at the transmitter for rotating the reference antenna.

Field strength measurements should be made along at least eight radial paths from the transmitting antenna. These paths should include the direction(s) of maximum radiation, the direction(s) toward stations requiring protection, and at least two additional directions toward the service area of each station requiring appreciable protection. For each direction, measurements of the signals received from the main and reference antennas should be obtained in at least eight measuring locations at distances between 10 and 30 miles. The measuring locations should be selected so as to provide a clear, unobstructed path to the transmitting antenna, and the reference antenna should be rotated for maximum received signal. The ratio of the signals from the reference and main antennas should be established either by means of short mobile runs made by the continuous recording technique, or on the basis of the average results of four cluster measurements at points located at least 50 feet apart.

Measurements should be made at the visual carrier frequency at each measuring location. At approximately half of the measuring locations, measurements should also be made at the color subcarrier frequency and at the aural carrier frequency. Field strength measurements may be made with a receiving antenna height of approximately 10 feet.

Measurements should also be obtained at the visual carrier frequency along cross minimum routes through those arcs which include the service area(s) of other station(s) where suppression is required. These should be made at distances between 10 and 30 miles, and point ratio measurements should be obtained at intervals ranging from three to four degrees in the case of suppressions on the order of 10 db to 1 or 2 degrees for suppression on the order of 17 db. At all measuring points, the reference antenna should be positioned for maximum received signal and measurements should be made of the signals from both the reference antenna and the main antenna.

The operational antenna pattern should be established by analysis of the ratio measurements using the average or median ratio obtained for each radial direction. The ratios for each radial direction should be plotted vs distance and the resulting graphs should show no significant correlation with distance, except as expected because of the difference in vertical patterns of the two antennas. The radiation determined for each direction should be referred to the radiation in the direction of maximum radiation.

The suppression obtained at visual carrier frequency should meet the requirements set forth under the Conclusions to this paper. It is suggested that suppression at the color subcarrier and aural frequencies be within ±2 db of the suppression measured at the visual carrier frequency.

Monitoring points should be selected in each critical direction. These points should provide unobstructed paths to the transmitting antenna. If the cluster measuring method is employed, at least six points should be measured and the exact location of each of the cluster measuring points should be permanently established. Ratio measurements should be made at the monitoring points at monthly intervals to insure that the operational pattern is properly maintained.

CONCLUSIONS

Factors beyond the control of TASO and the Directional Antenna Committee made it necessary to restrict the tests to measurements which were expected to provide an answer to the two problems set forth in the terms of reference of the Committee previously quoted. Tests were conducted at only two sites employing only one basic type of directional antenna, and any conclusions which are drawn must be made with full appreciation of the limitations thus imposed. Measurements made upon directional antennas of other types or having a more complicated structure and/or located in rough terrain or large metropolitan centers might show greater deviation from the expected results. However, the uniformity of the results obtained in these tests would tend to indicate that if sufficient care is employed in using directional antennas as an instrument of allocation, the antennas can be depended upon to perform in the manner intended. From the experience gained from future operation of directional antennas by operating television stations, it is to be expected that the limited conclusions reported here can be expanded and augmented in the same fashion as this information was obtained by the operation of directional antennas in the standard broadcast band.

Based upon the results of the tests just described and keeping in mind the limitations thereon, the following conclusions have been reached.

1) The operational antenna pattern, that is to say, the pattern measured with the antenna installed on its supporting structure at the transmitter site, can be accurately established after installation by field measurements, using either the reference antenna or rotational techniques.
2) Measurement of the operational antenna pattern after final installation is considered essential to insure that the suppression intended is actually obtained. Such measurements will not only show the influence of nearby objects on the operational pattern, but will also permit correction of any possible irregularities in the antenna pattern caused by damage during installation or improper connections and adjustments.
3) The reference antenna method is probably more practical and feasible than the rotational method in the case of actual operating antennas. For accurate results, the reference antenna must be designed to insure low coupling to the main antenna elements, tower structure and guy wires. Utilization of the rotational reference antenna eliminates the necessity for an accurate radiation pattern of this antenna.
4) The methods employed in these tests are not suitable for determining the vertical directivity of the operational antenna pattern, although a small but important sector thereof can be studied by an analysis of ratio measurements made over a limited range of distances by the reference antenna meth-

od. Because of this limitation, the antenna manufacturer must be relied upon to provide information on the vertical pattern characteristics. In making measurements on antennas with unusual heights or large beam tilts, the effect of the vertical plane pattern on the measured ratios at various distances should be considered when selecting the range of distances over which the measurements are to be made.

The question of the amount of fill in the directions of maximum suppression is of course most important. This fill is a function not only of the depth of the suppression but also of the steepness of the sides of the pattern. As applied to the Television Allocations problem, suppression will generally be required over a relatively wide arc. Consequently, the use of directional antennas with high degrees of suppression and steep sides is not likely.

The observations at WKY-TV showed that with a suppression of 20 db in the operational pattern at considerable distances from the transmitter, measured suppression of 16 to 17 db could be counted upon, and the average over a long period of time approximated the calculated 20-db value. It would appear that for the present, at least, a suppression of 20 db is too great to be used with confidence that the intended suppression would be obtained in practice. On the other hand, suppressions on the order of 10 db appear to present no problem.

Until further experience is gained, we believe that directional antennas should not be used to provide protections greater than 15 db (ratio of major lobe to minimum). To provide for possible propagation "fill in" effects, the operational pattern should indicate somewhat greater suppression than that required to meet the protection requirements. Until further knowledge is available, it is suggested that a "fill in factor" of 2 db be used for suppressions in the order of 15 db and that the factor be reduced to zero for suppressions less than 10 db. For example, if calculations indicate that a suppression of 15 db is required, the directional antenna should be designed for 17 db and this figure should be obtained in the operational pattern.

Distinct from this problem is the appearance of ghosts when the radiation is suppressed to the order of 20 db as, for example, in the WKY-TV case. Reflections of the main beam from nearby objects may reach a magnitude equal to, or greater than, the direct signal. In selecting a site for a television station which would require a directional antenna having a high degree of directivity, it would be desirable to locate the transmitter so that the suppressed direction is toward the area of lowest population density.

The conclusions expressed herein are those of the authors of this paper, and they do not necessarily reflect the conclusions of the Directional Antenna Committee or of TASO.

Sound-to-Picture Power Ratio*

K. McILWAIN†, FELLOW, IRE

Summary—**During the Television Allocations Study Organization's deliberations the question of lowering the television sound-to-picture power ratio from 50 per cent to 10 per cent was raised to determine its effect on allocation policy. The transmitter engineers favored it as simplifying the transmitter and reducing its price. The receiver engineers opposed it as reducing the useful range of the receiver and complicating its design. While TASO made no recommendation on the question, it is the author's personal opinion that it is best to leave well enough alone.**

WHILE the consideration of a reduction in the sound-to-picture power ratio of the United States Standard Broadcast television system had been discussed before, serious action on this subject in TASO was triggered off by a statement by E. W. Allen, Chief Engineer of the Federal Communications Commission, that he believed that the choice of this ratio could have an influence on allocations. This is because the usual limitation on adjacent channel spacing is the interference from the undesired sound signal in the lower frequency channel adjacent to the desired channel. Lowering the sound power might well extend the range of the higher frequency channel.

This remark stirred up considerable activity in both Panel 1, Transmitters and Panel 2, Receivers. Some interest was also generated in Panel 3, Field Tests and in Panel 5, Analysis and Theory. This paper is the history of the subsequent controversy as it developed in TASO.

The original sound-to-picture power ratio allowed in the FCC monochrome regulations ranged from 50 to 150 per cent. In the color television regulations this range was reduced to 50 to 70 per cent. This made little

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* Original manuscript received by the IRE, February 3, 1960; revised manuscript received March 1, 1960.

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practical difference since almost all stations were then operating near the 50 per cent limit. It was suggested that the ratio be lowered to 10 per cent—a decrease of 7 db.

There is no question that the 50 per cent figure gives an aural range considerably greater than the picture range and that this increased range is used. The author has seen receivers at Riverhead, Long Island, N. Y., reaching 70 miles to pick up New York City. The pictures were, at best, ghostly outlines, but the sound was fine and the people watched and listened. A. J. Ebel "can report from three years viewing experience with inferior signal that so long as the sound level was maintained much enjoyment and/or information could be obtained from TV programs even though the picture was of very poor quality or faded out completely. On the other hand, when the sound would fade, the content of the program was lost even though the picture held." Our experience with radio has trained us to fill in, while the television performers are not, in general, skilled pantomimists. Since the system is used under these conditions let us now examine the effects of making a change in the present standards.

As far as TASO is concerned, the three ratios discussed were the present 50 per cent, 20 per cent, and a lower limit of 10 per cent.

Several criteria of comparison have been put forward. Let us examine them one by one, starting with the less controversial (if there are any).

RECEIVER INTERFERENCE

The report of Committee 1.4 of TASO points out at least two forms of interference which would be decreased, namely sound into video and the 900-kc beat in color reception. Obviously for a given design, for less sound power there would be less sound interference.

The TASO Committee 2.6 report points out, however, effects in the receiver which they regard as much more serious. The effects of a reduction in transmitted aural power from present standards on typical modern television receivers will now be considered.

Thermal Noise Performance[1]

A reduction in transmitted aural power will result in poorer receiver signal-to-thermal-noise ratio which will, by reduction of receiver fringe area sound performance, reduce the sound coverage of any given transmitter. To obtain experimental verification of the reduction of sound channel thermal noise performance, measurements were made on nine different receivers in the engineering laboratories of some of the members of TASO Panel 2. Four different types of FM detector systems are represented in these receivers covering every type in use today. In all cases, measurements are for one of the lower VHF channels. Fig. 1 presents the data of one of these receivers which is typical of the group. Sound channel signal-to-noise output ratio is plotted as a function of picture-to-sound input ratio for a number of picture carrier signal levels. It can be seen that for each signal level there is a threshold value of picture-to-sound ratio below which the signal-to-noise ratio degrades rapidly. Fig. 2 presents a summary of these data for all the measured receivers. The loss of sound channel signal-to-noise ratio per unit reduction in sound carrier is plotted as a function of picture carrier level. In these data the average of all the receivers is presented and the data for the measured extremes are also plotted. As an example, from this curve it can be seen that with 20 microvolts (−34 db) of picture signal (open circuit antenna voltage delivered through a 300-ohm dummy antenna to the receiver), an average loss of about 1.5 db in signal-to-noise ratio will occur for each db of aural carrier power reduction. These data are for new, aligned receivers of modern design. If we add the losses expected due to misalignment, tube aging and antenna orientation and mismatch, as well as transmission line losses, it is reasonable to expect that this type of signal-to-noise ratio loss would occur in the 100- to 200-microvolts-per-meter range of signal strength in a substantial number of receivers currently in the hands of the public.

Sound quieting sensitivity which takes into account only thermal noise considerations is 30 microvolts for the typical receiver in the group used to obtain these data. In the report on receivers prepared by Committee 2.1 of Panel 2, the reported picture sensitivity for 78 receivers in the low VHF channels varied from 4 to 150 microvolts.[2] The distribution of sensitivity shows:

12.8 per cent less than 10 microvolts
34.6 per cent between 10 and 20 microvolts
19.2 per cent between 20 and 30 microvolts
11.5 per cent between 30 and 50 microvolts
9.1 per cent between 50 and 100 microvolts
12.8 per cent greater than 100 microvolts.

The importance of fringe area performance may be judged by the fact that more than 66 per cent of the receivers reported picture sensitivities better than 30 microvolts.

Impulse Noise Rejection Performance[1]

A common form of noise interference in the sound channel is that caused by automotive ignition noise, electric motor commutator noise (shavers, mixers, vacuum cleaners, etc.), arcing switches, and lightning. This form of noise is usually lumped under the general heading of impulse noise. In order to measure the effect of aural carrier power reduction on receiver performance in the presence of this form of noise, an interference source, such as a nonsynchronous 60-cps rotating arc device, was coupled through a variable attenuator into

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[1] The text and figures in this section are taken from the report of TASO Committee 2.6.

[2] See Table III of W. O. Swinyard, "VHF and UHF television receiving equipment," this issue, p. 1069.

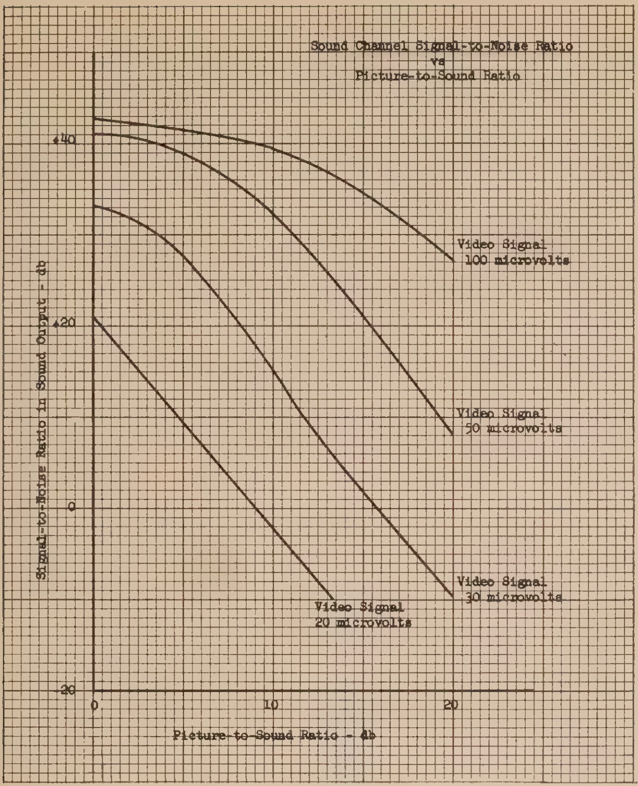

Fig. 1.

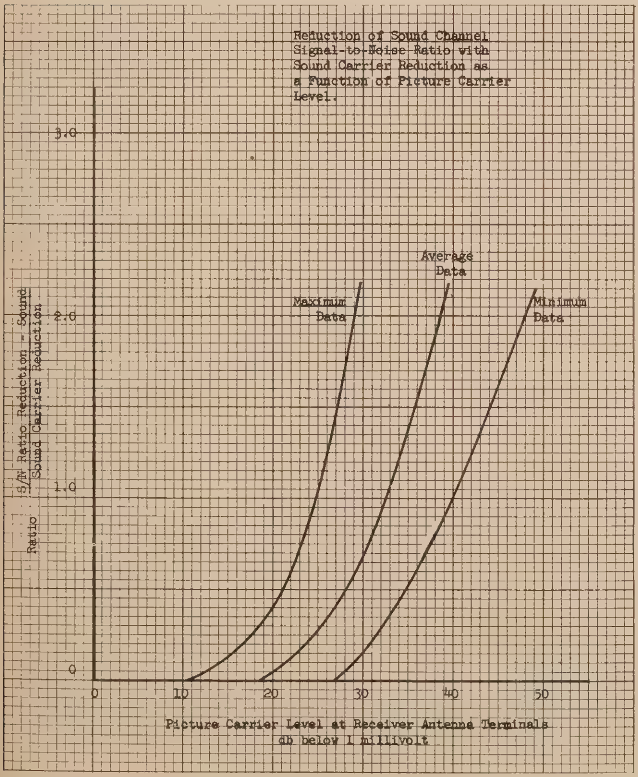

Fig. 2.

the antenna circuit of the test receiver in parallel with the desired standard visual and aural television signal. The interference noise signal input to the receiver was increased until its presence was noted in the sound output of the receiver either by aural or measured output detection. The aural signal was then reduced in steps and at each step the change in noise interference required to restore the original condition was recorded. Data were obtained on seven different commercial receivers, independently measured in the laboratories of Panel 2 members, and data for a typical receiver are plotted in Fig. 3 for visual signal input levels ranging from 50 to 10,000 microvolts. Fig. 4 presents a plot of data for the relative impulse noise level for constant audible interference as a function of sound-to-picture power ratio. This is the average of all data for all seven receivers measured. A loss of tolerance to impulse noise of about 1 db for every decibel of reduction in aural power is noted. This performance loss occurs at strong signals as well as weak; the performance loss with reduction of aural power is as great at 10,000 microvolts as it is at 50 microvolts. As in the previous case for thermal noise, these data are for new, aligned receivers of modern design.

Costs

The transmitter engineers report that the cost savings of from 10 per cent to 40 per cent resulting from a change of picture-to-sound power ratio from 2:1 to 10:1 may be of importance to a television station. The approximate savings, based upon the Committee 1.1 report, for the 10:1 ratio are as follows:

VHF

$\frac{1}{2}$ kw visual power rating	27 per cent
5 kw visual power rating	30 per cent
10 kw visual power rating	30 per cent
25 kw visual power rating	40 per cent
50 kw visual power rating	40 per cent

UHF

$\frac{1}{10}$ kw visual power rating	10 per cent
1 kw visual power rating	10 per cent
12 kw visual power rating	30 per cent
25 kw visual power rating	10 per cent
45 kw visual power rating	20 per cent

Loss of Service Area[1]

The savings in cost of operation must of course be measured against the decreased population the transmitter will serve even though partially. In order to show the loss of aural service area resulting from a reduction of sound power, the required field strength in decibels above 1 μv/meter to produce 30-db quieting was determined by measurement of the quieting sensitivity for representative TV receivers under existing transmission standards and calculation of the equivalent field strength using the formula and data presented in TASO Committee 2.4's report. The average figures for antenna gain and transmission line losses were used for channels 4 and 10 which are about in the middle of the two fre-

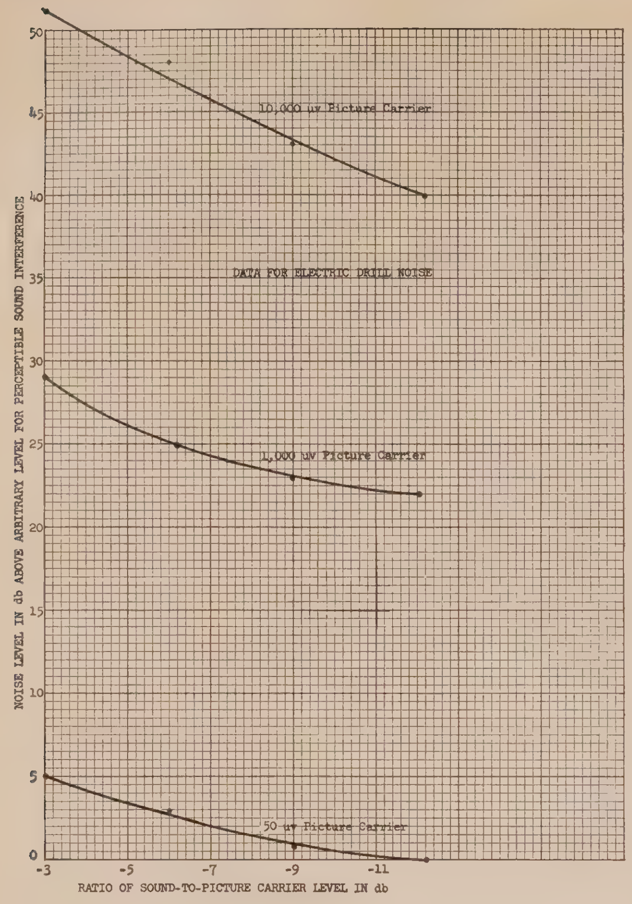

Fig. 3.

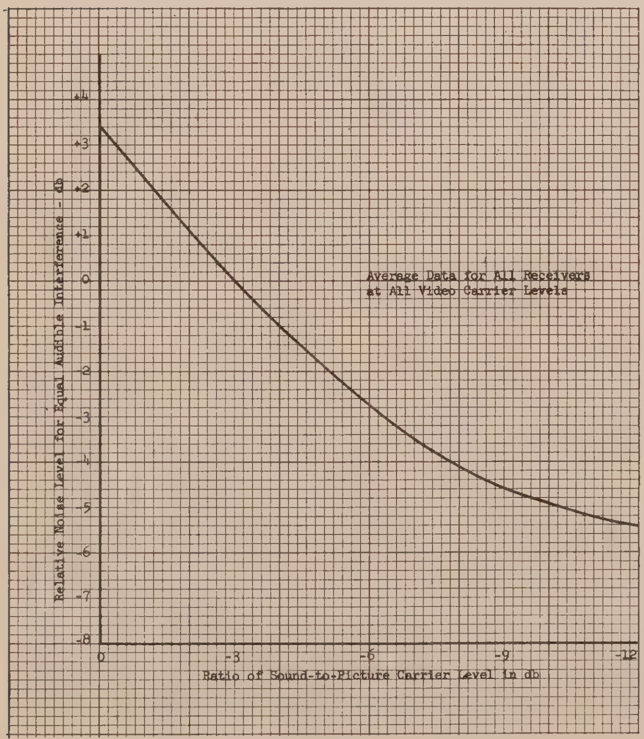

Fig. 4.

quency ranges. The required increase in video and sound signal levels to compensate for a reduction in sound power with respect to video power was determined to be 0.57 db for each decibel drop in sound power. This was obtained from the average degradation in signal-to-noise ratio at the 30-db level in data furnished by members of Committee 2.6.

Finally, the reception range and loss of service area were determined from the FCC curves of expected field strength, assuming maximum authorized power in the TV transmitter, and representative antenna heights.

Figs. 5 and 6 show the loss of service area for VHF channels 2–6 and 7–13 resulting from a reduction of sound power below the present minimum of 3 db below the peak video power. The service area is reduced about 20 per cent on the low VHF channels and about 10 per cent on the high VHF channels if a 7-db reduction in sound power is made. This assumes that service area is limited by the signal-to-thermal-noise ratio.

First NTSC

Both sides quote the first NTSC report. The reduced sound adherents quote that the first NTSC Panel 4 originally recommended visual-to-aural ratio of 4:1 to 8:1.

The unreduced sound adherents point out that the first NTSC recognized that the public will tolerate and be entertained by extremely marginal picture signals provided satisfactory sound signals are available. In the report of the first NTSC in 1941, it is stated, "a given amount of interference is more disturbing in the sound than in the picture. The service area of the television system will be determined by the acceptability of the service with respect to the noise interference."

Since the first NTSC reported almost twenty years ago and its members were not endowed with second sight, the quotation of these opinions looks like grasping for straws.

Elimination of Equipment Consideration

All of the arguments listed above seem to this reviewer largely to cancel out; moreover, it had been agreed by TASO to reject economic arguments unless related to the problem of allocations. In fact, the interim report of Panel 5 states: "Though there would be some savings possible to broadcasters through equipment simplifications and some reduction in power cost, it has been agreed in TASO that this is not significant to allocations and is therefore not a consideration."

Adjacent Channel Interference[1]

One consideration which seems at first blush to have an influence on allocations is the interference in the picture from the nearby sound signal of the next lower channel (exists on channels 3, 4, 6, and 8 through 13). The interfering sound carrier is only 1½ megacycles from the desired picture carrier.

The unreduced sound power adherents counter with this argument. Granted that a reduction in transmitted

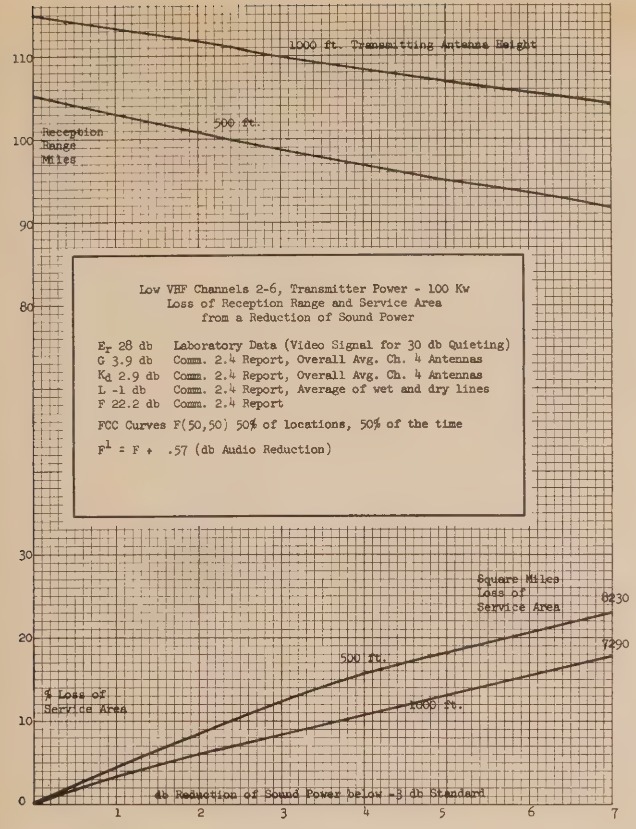

Fig. 5.

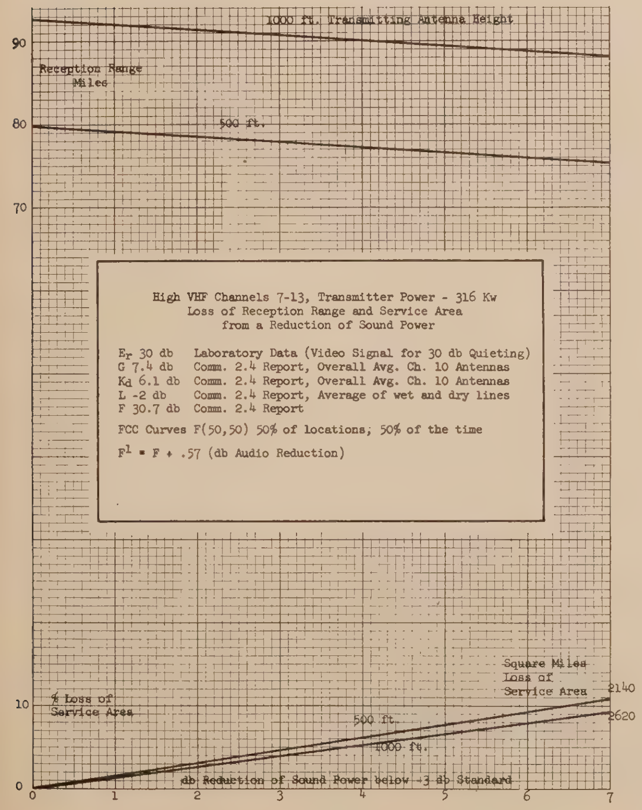

Fig. 6.

aural power would reduce the lower adjacent channel sound interference in those areas where it now exists by an amount equal to the sound power reduction. Examination of the receiver report of Committee 2.1 of Panel 2 shows that receiver attenuations for the lower adjacent channel sound signal vary widely, ranging from 14 db to 60 db, distributed as follows:[2]

11.8 per cent less than 30 db
42.1 per cent between 30 and 40 db
13.1 per cent between 40 and 50 db
32.9 per cent greater than 50 db.

This wide variation is a reflection of the fact that this performance characteristic is determined by competitive pressure in particular areas rather than by a universal requirement.

The fact that competitive pressure determines receiver adjacent channel rejection capabilities in most cases means that for any small variation in adjacent channel interference, such as would be accomplished by a 7-db reduction in sound power, the net improvement could be relatively short lived, as new designs under economic pressure would tend to seek the same competitive level as is now considered satisfactory. Conversely, any increase in adjacent channel interference, such as might result from a permitted *increase* to *both* picture and sound power might result in no long term degradation in adjacent channel performance as competitive pressure would force receiver manufacturers to build more adjacent channel rejection in receivers.

SURVEYS

Several surveys were conducted under various conditions ranging from asking servicemen to make two measurements a day while three stations voluntarily varied picture-to-sound power ratios at random all the way from 2:1 to 10:1, to one station which had to run at reduced power because of antenna difficulties but experienced no customer complaints. There was no clear indication from any of these. People are prone to turn up the volume control, to lay difficulties to a change in the weather, or just not to remember. A trained observer turning immediately from one simple sound to compare it with a similar sound can discriminate about 1 db. Whether an untrained observer, after a time interval, and comparing one complex sound with an entirely different one can remember a difference of 5 db is doubtful, except where it makes the difference of being able to understand or not. Suffice it to say, there is no proof that anyone noticed the degraded service and protested. It is not, however, certain that at the fringe area, the percentage of usable broadcasts was or was not decreased.

We know that a usable signal for any individual is determined by his judgment of whether it is worth the effort to try to read it. The strong sound folk have shown that a decrease in the strength of the sound inevitably makes the signal-to-noise ratio worse and therefore makes the signal harder to read.

Since present receivers have been designed to eliminate largely the various interferences and, therefore, are practically noise-limited, and since, with respect to this characteristic, at least the good receivers are working at the limitation of the state of the art it would appear to this reviewer that less harm would be done by leaving the sound level near what it is and devoting our time to improving noise figure and other qualities of the receiver.

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[8] Final Report of TASO Panel 2, Committee 2.6, "Sound-to-Picture Power Ratio" (D659P2.47).

[9] Final Report of TASO Panel 3, Committee 3.3, Part II, "A Study of Television Aural-to-Visual Power Ratio at VHF," p. 41 (D579-1P3.38); Date.

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Presentation of Coverage Information*

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Summary—**Two methods for calculating the locations of boundary contours defining the limits for various grades of television service are described and discussed. The first is the location probability method, which has been used by the Federal Communications Commission for the past ten years in its allocation and channel assignment operations. The second is the newly developed acceptance ratio method, which emerged from the work of the Television Allocations Study Organization.**

INTRODUCTION

THROUGHOUT the life of a television broadcasting station, occasions arise when it is desirable that means exist for estimating how large an area can be reached by its programs and how this area is disposed geographically. It is also of interest to know how quality of reception varies over this area. These questions have been of particular interest to the Federal Communications Commission because of its responsibility for assigning television channels in such a way as to provide a maximum amount of service to a maximum number of people. It is also of interest to individual broadcasters since their ability to attract sponsors for their programs is a function of the number of people who can be reached by their commercial messages.

In 1949, a method for developing such information was deduced by a special committee of the Federal Communications Commission.[1] Since then, the method has been used by the Commission to assist in the determination of whether the licensing of a proposed new station will be consistent with the over-all allocation plan. Within the past several years, the method has been examined by the Television Allocations Study Organization (TASO) in its studies on television coverage presentation methods and has been endorsed as the best method available. At the same time, TASO regarded the method as too complicated mathematically, particularly in view of the admitted deficiencies in certain experimental data with which use of the method was necessarily coupled. It seemed worth while to attempt to develop a new method which had a simpler mathematical form and which would avoid the use of experimental data of questionable accuracy. In the course of an effort to accomplish this purpose, a new method was conceived by Dr. Bowie[2] and studied in detail by TASO Panel 5.[3] Although it was concluded that the new method represented a restricted special case of the old one and would be inapplicable in many actual situa-

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* Original manuscript received by the IRE, February 16, 1960.

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[1] "FCC, Report of Ad Hoc Committee for Evaluation of Radio Propagation Factors Concerning Television and Frequency Modulation Broadcasting Services in Frequency Range Between 50 and 250 Mc," FCC, Washington, D.C., vol. I, May 31, 1949; vol. II, July 7, 1950.

[2] R. M. Bowie, "The television system from the allocation engineering point of view," this issue, p. 1112.

[3] "Engineering Aspects of Television Allocations," Rept. of TASO to FCC, pp. 359–362 and 366–368; March 16, 1959.

tions, it was nevertheless considered to possess features of mathematical simplicity more consistent with the accuracy of the available experimental data with which it would be used than was the old method. In short, it was considered that both methods would be of value under appropriate circumstances.

Until the present time, neither method has been adequately described and explained in the readily accessible technical literature. The purpose of the present paper is to overcome this deficiency. The technical discussion will begin with a description of the older of the two methods, known as the location probability method. This will be followed by a similar treatment for the new method, which has come to be known as the acceptance ratio method.

Location Probability Method

Discussion of the location probability method conveniently begins with introduction of the concept of a *cell.* A cell will be defined as an area on the ground in the field of a transmitting antenna radiating a desired signal. The cell will be required to have dimensions which permit it to satisfy simultaneously the following two conditions:

1) The dimensions must be small enough so that the locations of all points within the cell relative to the transmitting antenna can be described to an acceptable first approximation by the same distance and direction angle. In essence, this means that the linear dimensions of the cell must be small compared with the distance between the transmitting antenna and any selected point within the cell. It follows that cells near the transmitter must be quite small while those further away can be larger in direct proportion to their distances.

2) A cell must have large enough dimensions to permit it to enclose a population of uncorrelated receiving sites from which statistically representative samples, small compared with the total population, can be taken by random selection. By "uncorrelated" is meant that detailed knowledge of the reception conditions at one site does not permit one to infer in detail the reception conditions at any other site in the population. By "statistically representative samples" are meant assemblages of sites yielding distributions of receiving conditions having essentially the same median values and standard deviations as those for the full population.

It is to be noted that these two requirements are necessarily mutually exclusive at locations within some critical distance of the transmitting antenna. That is, when the cell is small enough to satisfy the first condition mentioned above, it may be too small to satisfy the second condition. Thus, there is always a region of indefinite extent around the antenna which cannot be divided into cells. Within this region, the concepts to be developed in this paper cannot be applied without some modification in the basic philosophical approach, but it will eventually be seen that this consideration is of only academic interest.

Consider the field $E(t)$ at an individual arbitrarily selected site within some given cell. This field is likely to vary with time in some such manner as shown in Fig. 1. Over any relatively short interval of time, the field strength may tend to fluctuate in a random manner about a fairly well-defined median value. This is the case for the interval depicted in Fig. 1. When longer intervals are considered, however, it is likely to be revealed that the short-term median value is itself a function of time, being lowest during the afternoon hours and increasing steadily after sunset. Thus, the short-term median field shows a diurnal variation. Similarly, it shows a seasonal variation, tending to be higher during the summer than during the winter.

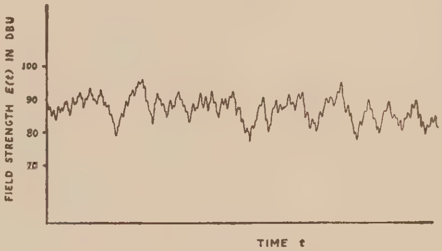

Fig. 1—Typical time variation of field strength $E(t)$.

When $E(t)$ data for the field at the selected site are available for an interval of time long enough to permit the averaging out of components due to diurnal and seasonal variations, it becomes possible to construct from the $E(t)$ data a new function $F'(T)$ which is fully independent of time. This new function is to be defined so that the symbol $F'(T)$ represents that value of field strength which is exceeded at the given site for exactly T per cent of the above-specified sufficiently long interval of time. It then follows, for example, that $F'(50)$ represents the long-term median field strength. It also follows that the smaller the value of T, the higher is the value of $F'(T)$. Although this point is of only academic interest, it will also be noted that the values associated with the symbols $F'(0)$ and $F'(100)$ cannot be unique unless special qualifications are placed on their definitions. Suppose, for example, that the lowest field ever encountered at the given site is F'_{min}. Then, according to the definition already given, the symbol $F'(100)$ might be applicable to any field strength less than F'_{min}. In the same way, any field strength greater than F'_{max} might be denoted by the symbol $F'(0)$. This multiplicity is readily eliminated by the adoption of a pair of special definitions $F'(0) \equiv F'_{\text{max}}$ and $F'(100) \equiv F'_{\text{min}}$.

When $F'(T)$ is plotted as a function of T, the result is a curve such as that shown in Fig. 2. Although this curve may show considerable variation in form for data from different receiving sites, its slope is always negative along its entire length. It is instructive to note that the same curve could have been derived from the same data in another way. First, the abscissa and ordinate scales in Fig. 1 would be subdivided into large numbers of narrow intervals with the number of intervals in the abscissa scale greatly exceeding that in the ordinate scale. The two sets of intervals would define a rectangular grid subdividing the curve into a large number of short segments. Each segment would be characterized by a pair of ordinate and abscissa values referring to the pair of scale intervals within which it occurred. A new curve would next be drawn, showing the number of segments falling within each ordinate interval as a function of the ordinate value belonging to that interval. This plot would be a frequency function indicating the relative frequency with which any given field strength occurred, and might appear as in Fig. 3. Finally, a graph would be drawn to display as a function of the abscissa values in Fig. 3 the area lying under the curve and to the right of each abscissa. The abscissa values in Fig. 3 would be plotted along the ordinate scale in the new diagram, and the areas would be plotted along the abscissa scale in terms of the parameter T, which represents the area in question divided by the total area under the entire curve in Fig. 3. The resulting curve will be recognized as representing a cumulative distribution function. This curve is also identical with that in Fig. 2.

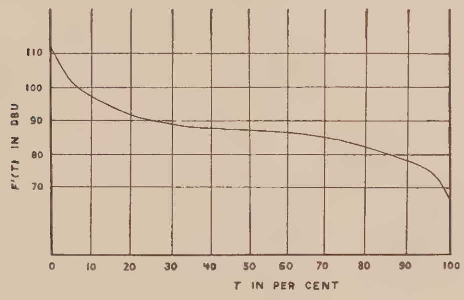

Fig. 2—Function $F'(T)$ corresponding to $E(t)$ in Fig. 1.

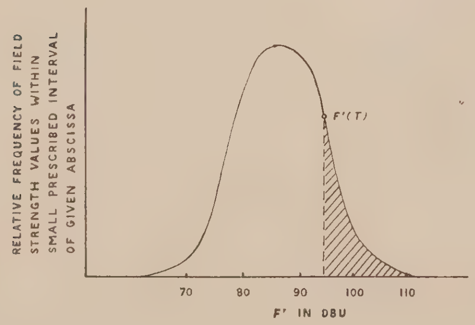

Fig. 3—Frequency distribution corresponding to Fig. 1. Shaded area is T per cent of total area under curve.

In what follows, a field strength value which is exceeded at a given site for exactly T per cent of a suitably long period of time as defined above will be called a *T per cent field*. Thus, $F'(T)$ denotes a T per cent field, and it would become meaningful, for example, to speak of 60 dbu[4] as being the 70 per cent field at a given site. Now consider not just one site within a given cell but all of the sites in a statistically representative sample of the population of uncorrelated sites in the cell. Let $E_i(t)$ and $F_i(T)$ be the field strength and the T per cent fields, respectively, at the ith site in the cell. Corresponding to any arbitrarily selected value of T, there exists a definite value of $F_i(T)$ at every site, and it is to be expected that the value at one site will generally differ somewhat from that at another site in the same cell unless the terrain around and within the cell is flat and the corresponding air space unobstructed. The distribution of values of $F_i(T)$ corresponding to a given value of T would be expected to be a function of the terrain roughness, and it is intuitively reasonable to expect the median value of $F_i(T)$ in the distribution to be primarily a function of distance to the cell from the transmitting antenna, contour of the intervening terrain, effective height of the transmitting antenna, etc., and to expect the standard deviation of values about this median to increase with the roughness of the terrain in and around the cell in question.

It will shortly become necessary that some sort of assumption be made about the manner in which the $F_i(T)$ values for a given value of T are distributed about their median. In both the original Ad Hoc Committee Report[1] and a more recently published discussion[5] of the location probability method, the mathematical formulation was patterned in a way which tacitly assumed a normal distribution. This, however, does not mean that some other form of distribution could not be used just as readily in the formulation. Published data show that a normal distribution is indeed approached when the cell is expanded along a circular arc with the transmitting antenna at its center. But this type of cell, since it does not comply with the definition given earlier in this paper, will not be considered further. In the case of cells of the type defined in this paper, there appears to be a scarcity of published data on which to base a reliable determination of what type of distribution is more likely to be encountered, but the available data seem to suggest that a Rayleigh distribution is more likely to provide a satisfactory fit with the data than is a normal distribution. There is also theoretical reason for expecting that this might tend to be the case.

Next to be constructed is a graphical representation of the distribution. This construction begins with selection of a suitable interval $\Delta F'$ in the range of F' values. A coordinate system is then laid out with the scale of F' values arranged along the abscissa axis. A smooth curve is then drawn in such a way that its ordinate at each point approximates the number of $F_i'(T)$ values lying within the selected interval $\Delta F'$ of the abscissa of the point. If $\Delta F'$ has been chosen small enough, the curve will represent the frequency function for $F_i'(T)$ corresponding to the specified value of T. It might appear as shown in Fig. 4, which depicts the distribution of $F_i'(40)$ values among a set of sites in a given cell. As the value of T is varied, it is to be expected that the form and position of the curve might shift. It is clear from what has preceded that increasing the value of T will cause the position of the curve to shift to the left. The effect on the shape of the curve cannot be inferred at this point.

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[4] DBU denotes decibels above a field strength of 1 μv per meter.

[5] E. W. Allen, "Wave propagation, radiation, and absorption," in "Television Engineering Handbook," D. G. Fink, Ed., McGraw-Hill Book Co., Inc., New York, N. Y., ch. 14, pp. 26–32; 1957.

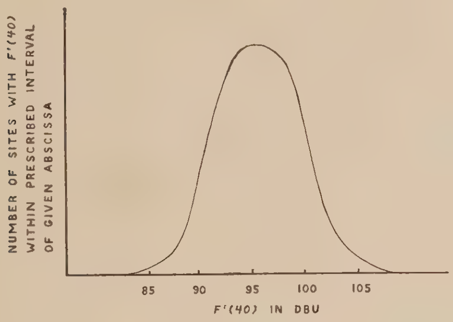

Fig. 4—Typical distribution of $F_i(40)$ values over sites in given sample.

At this point, the requirement that the data are to be taken at a statistically representative set of uncorrelated sites is to be invoked. From this requirement and from the definition of a cell, it follows that the forms of the distributions of the type shown in Fig. 4 should not be sensitive to the method used in choosing the set of statistically representative sites and should not even vary significantly from one cell to an adjacent one. In fact, the entire concept of a cell with finite area could be abandoned at this point. Instead of dealing with sets of sites in cells and calculating median fields and considering frequency functions relating to sets of data taken from discrete uncorrelated sites, one might now deal instead with probability functions for the field at a given site. The appropriate probability function would have the same form as did the corresponding frequency function for the statistical assemblage. The median field would be replaced by the most probable field if the frequency function is symmetrical, and the uncertainty in the prediction would be measured by the standard deviation in the frequency function. At a later point in this development, it will be desirable to adopt the probability approach for values at a single point. For the present, however, the purposes of clarity will best be served by retaining the statistical point of view involving cells and sets of uncorrelated sites.

The purpose of the next step in the development of the location probability method is to provide means for determining the answer to this question: Given a particular cell and given a particular statistically representative set of receiving sites in that cell, what percentage L of the sites in this set can be expected to exhibit fields which exceed some prescribed field strength level F' for at least some preassigned percentage T of the time? To answer this question, one can begin by determining the T per cent fields $F_i'(T)$ at all of the sites, T being the preassigned percentage T of the time, and continue by constructing from these values a frequency curve of the type shown in Fig. 4. There can then be constructed at the abscissa corresponding to the prescribed field strength level F' a vertical line which divides the area under the frequency curve into two parts. Now the total area under the curve represents the total number of sites in the given sample, the area to the right of the vertical line represents the number of sites having $F_i'(T)$ values larger than F', and the area to the left represents the number having values smaller than F'. From the meaning of the quantity $F_i'(T)$ as illustrated in Fig. 2, it should be intuitively clear that if the T per cent field at a given site is larger than F', then there exists some T' larger than T such that the prescribed level F' coincides with the T' per cent field corresponding to T'. For example, let F' be 80 dbu, and let $T=40$ per cent. For the case shown in Fig. 2, the $F'(40)$ field has a value of about 88 dbu. However, there exists a value of T larger than 40 per cent such that the corresponding $F'(T)$ level equals the prescribed 80 dbu. This larger T value is seen in Fig. 2 to be $T=86$ per cent. It follows that all of the sites represented by the area to the right of the vertical line have fields which exceed the value F' for *at least* T per cent of the time. Exactly analogous reasoning reveals that all of the sites represented by the area to the left of the line have fields exceeding F' for less than T per cent of the time. Thus, the desired percentage L of the sites having fields exceeding level F' for at least T per cent of the time is the ratio of the area to the right of the vertical line to the entire area under the curve. Hereafter, the symbol F' will be replaced by the symbol $F'(L, T)$ to denote that it is a function of both L and T.

$F'(L, T)$ can be plotted as a function of L for any fixed value of T by constructing the previously described vertical line at various abscissa positions on the $F_i'(T)$ frequency curve and plotting these abscissas as a function of the corresponding area ratios. The resulting curve is a cumulative distribution function similar to that in Fig. 2, the shape of the plot arising in any given case depending, of course, on the particular form of the $F_i'(T)$ function for that case. Through suitable application of nonlinearity to the abscissa scale of such a graph, one can easily test the data to determine to what type of distribution they belong. It has been most customary to assume a normal distribution for such data, for which the corresponding test involves the use of *probability coordinates*. Coordinates of this type are shown in Fig. 5 with the $F'(L, 40)$ distribution derived from Fig. 4 plotted against them. The solid curve represents the actual data, while the dotted straight line represents the normal distribution which fits it most closely. In the event that the $F'(L, T)$ data do not yield a nearly linear plot on probability coordinates, a reasonable next guess at the form of the distribution involved would often be a Rayleigh distribution. This hypothesis could be tested by replotting the data against a corresponding set of nonlinear coordinates.

It has usually been customary in working with the location probability method to assume that the $F'(L, T)$ values are normally distributed. This assumption can be expressed analytically by the formula

$$F'(L, T) = F'(50, T) + kN(L), \tag{1}$$

in which $N(L)$ is a prescribed standard cumulative normal distribution such that $N(50)=0$ dbu and $N(10)=20.5$ dbu. Being a cumulative normal distribution, $N(L)$ has a straight-line plot on probability coordinates and is therefore fully determined by the above two specified values. The quantity k is a constant with numerical values given by Allen[6] as 0.53 for VHF fields and 0.75 for UHF fields. $N(L)$ is shown in Fig. 6. In the event that the distribution under consideration is not normal, the standard reference distribution $N(L)$ for a cumulative normal distribution would be replaced by a corresponding function appropriate to the actual type of distribution. The ensuing Figs. 5 and 6 would then appear the same as in this paper except that the nonlinearity in the abscissa scales would assume a different form from that shown.

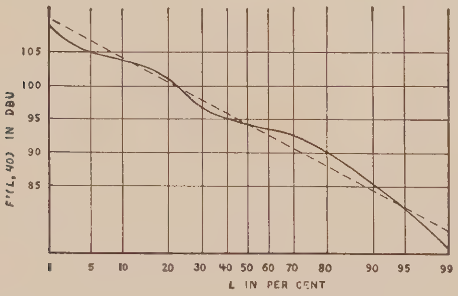

Fig. 5—Function $F'(L, 40)$ corresponding to distribution in Fig. 4.

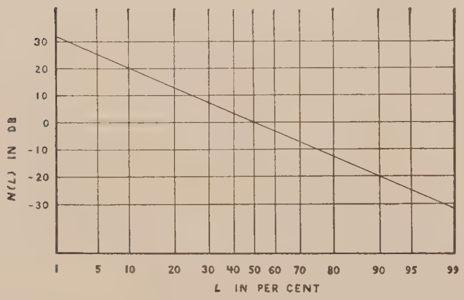

Fig. 6—Standard normal distribution function $N(L)$.

Just as the location probability method employs (1) to describe the distribution of $F'(L, T)$ in L in terms of a well-defined standard distribution law, it also employs a corresponding relation to similarly describe the distribution of $F'(L, T)$ in T in terms of a similar distribution law. Thus, (1) can be generalized, in the case of normal distributions in both L and T, to

$$F'(L, T) = F'(50, 50) + kN(L) + M(T), \tag{2}$$

in which $M(T)$ is a cumulative normal distribution such that $M(50)=0$ dbu, thereby making it a constant multiple of the standard cumulative normal distribution $N(T)$. $N(T)$, of course, is simply the previously introduced standard function $N(L)$ with the variable L replaced by the variable T. Before (2) can be used, means must be provided for determining values of $M(T)$ other than $M(50)$. The procedure supplied in the location probability method is based on the relation

$$M(T) = M(T_0)\frac{N(T)}{N(T_0)}, \tag{3}$$

which follows directly from consideration of similar triangles in Fig. 7, representing T_0 as having the value 10 per cent, although any other value would be equally usable. The curve $N(T)$ in Fig. 7 is the same as that in Fig. 6 except for the change in variable, and the curve $M(T)$ represents the straight-line approximation to the function $F'(50, T)$ which coincides with it at $T=T_0$ and at $T=50$ per cent.

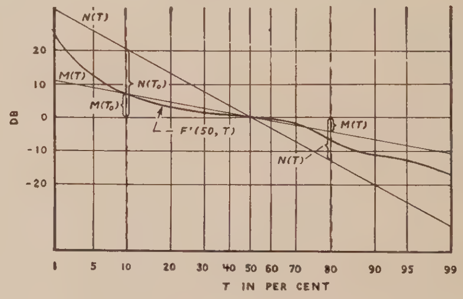

Fig. 7—Graphical interpretation of (3).

Eq. (3) by itself is not sufficient for the determination of $M(T)$, for this relation eliminates $M(T)$ only by exchanging it for the new quantity $M(T_0)$. In order to evaluate $M(T_0)$, one can set $L=50$ per cent and $T=T_0$ in (2) and solve for $M(T_0)$. The result is

$$M(T_0) = F'(50, T_0) - F'(50, 50). \tag{4}$$

Thus, evaluation of $M(T_0)$ requires knowledge of $F'(50, 50)$ along with $F'(50, T_0)$.

At this point, it is convenient to introduce the symbol $F(L, T)$, defined through the relation

$$F'(L, T) = P + F(L, T), \tag{5}$$

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[6] *Ibid.*, p. 31.

in which P is the effective radiated power of the transmitter. $F(L, T)$ is a normalized quantity which is conveniently presented through a family of curves. Curves for $F(50, 50)$ and $F(50, 10)$ are presented by Allen.[5] If T_0 is placed equal to 10 per cent in (4) and if (5) is then substituted into (4), one obtains

$$M(10) = F(50, 10) - F(50, 50), \qquad (6)$$

which is readily evaluated through use of the abovementioned curves. It is thus seen that, in the course of several steps, it becomes possible to deduce numerical values for any field strength level $F'(L, T)$ through (2), (3), and (6). Or, by altering the sequence of operations, one can solve for L after $F'(L, T)$ and T have been specified. As will be seen shortly, this latter procedure is the one which must be used in establishing service area boundary contours in accordance with the present FCC specifications for service of various grades.

The formulation as thus far developed is sufficient for application of the location probability method in the absence of interfering signals generated outside the receiving plant itself. It will therefore be convenient to interrupt the orderly evolution of the formulation at this point to describe how it is used in determining the limits of service of various grades in the absence of interfering signals.

In addition to the mathematical formulation already described, specifications must be provided for defining the performance characteristics of at least one, and perhaps more than one, standard reference receiving plant. It has been customary to base allocations and assignments on analyses involving the use of a single standard reference receiving plant at all distances from the transmitting antenna. However, there is no inherent limitation in the location probability method which compels such a procedure, and one could, if he so desired, carry out the procedure with different standard reference receiving plants for each of the different grades of service. In any event, one specification which must be provided for a standard reference receiving plant is the minimum field strength which must prevail at the antenna to provide a picture with acceptable signal-to-noise ratio. This ratio is called the *signal-to-noise acceptance ratio* and must be determined by subjective testing of a representative group of observers. No unique value for this ratio will arise from such tests, for different observers will exhibit different tolerance levels for noise in the picture. What the tests will yield is a distribution of acceptance ratios. The ratio, thereafter to be regarded as *the* signal-to-noise acceptance ratio, would then be defined as that tolerated by some prescribed percentage of the observers. If $F'(T)$ is now used to denote the field strength level at which the actual signal-to-noise ratio is just equal to the acceptance ratio at a given site, then T is called the *time availability of service* at that site. This name is based on the concept that *service* is said to be available at the given site as long as the signal-to-noise level is not less than the signal-to-noise acceptance ratio for the standard reference receiving plant. T in the present instance, of course, is the percentage of time for which the signal-to-noise ratio is not less than the signal-to-noise acceptance ratio and is therefore the percentage of time for which service is available.

Consider now the cell in which the given site is located. Because of the way in which the function $F'(L, T)$ has been defined, not only does there exist a definite numerical value in dbu for this function corresponding to any given pair of values for the parameters L and T, but there also exists a definite value of L corresponding to any given pair of values for the parameter T and the function $F'(L, T)$. In other words, one can regard L as a function of T and $F'(L, T)$ and can determine the value of L corresponding to specified values of T and $F'(L, T)$ if the form of the functional relation is known. This is what is done in determining what grade of service is available in a given cell. When T is the time availability of service and $F'(L, T)$ is the acceptance ratio for noise-limited service, then L is called the *location probability* for noise-limited service with time availability T. As currently defined, grade A service prevails in a given cell if the signal-to-noise acceptance ratio is exceeded for 90 per cent of the time at not less than 70 per cent of the sites. Grade B service prevails if this same ratio is exceeded at between 50 and 70 per cent of the sites for 90 per cent of the time.

The service area around a transmitter can thus be mapped by the above method into Grade A and Grade B areas if no interfering signals are present. The procedure would involve determining L for specified T and $F'(L, T)$ at each cell, designating as the Grade A and B service areas the assemblages of cells for which L equals or exceeds 70 per cent and for which L is less than 70 per cent but not less than 50 per cent, respectively. Such a map might appear as in Fig. 8 if the terrain around the transmitting antenna is only moderately rough. If the terrain is rougher, the resulting map would show a more tortuous contour accompanied by a larger number of enclaves and exclaves, both large and small. In such a case, arbitrary conventions might be adopted to simplify the contours, but this subject lies outside the domain of the present discussion.

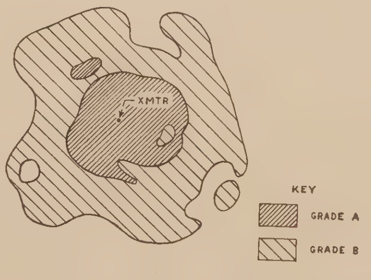

Fig. 8—Hypothetical contours for Grades A and B service.

Time availability and location probability have thus far been defined as attributes collectively held by all of the sites in a cell of finite dimensions. It is also possible to consider them as attributes of individual sites. This is accomplished by invoking the considerations cited earlier for arriving at the conclusion that one could abandon the concept of cells and deal on a probability basis with values at individual sites instead of on a statistical basis with values at an assemblage of uncorrelated sites within a given cell. When this is done, the distribution of field strengths actually observed among the assemblage of sites can be regarded as a *probability density distribution* for the field strength at any given site in the cell. Thus, the area lying under the frequency curve and bounded by a prescribed pair of abscissas represents the probability that the field at the given site lies in the range between the limits corresponding to the prescribed abscissas.

Next to be determined is the procedure for determining the availability of service when the degrading influence is contributed by interfering signals from another transmitter rather than by locally generated thermal noise. There are now two signal fields to deal with, a desired field and an undesired field, and each can be described in terms of its own $F'(L, T)$ functions in the manner already described. These functions will be designated as $F_d'(L_d, T_d)$ and $F_u'(L_u, T_u)$, respectively. Moreover, it will be supposed that the desired signal is always strong enough to override noise, so that service interruption occurs only when the desired signal fails to override the interfering signal by a sufficient amount. It now becomes necessary to define what amount is sufficient. This involves subjective evaluation of pictures which result when various ratios exist between the levels of desired and undesired signals at the receiver input terminals. The minimum such ratio which results in an acceptable picture is defined as the *acceptance ratio for the pertinent type of interfering signal.* Thus, there are co-channel, upper-adjacent channel, lower-adjacent channel, image frequency acceptance ratios and others, depending upon the natures of the interfering signals and the frequency ranges in which they lie.

When service is limited by interfering signals, the angle between the directions of arrival of the desired and undesired signals becomes of importance, and this brings the directivity characteristics of the receiving antenna into the discussion. Specifically, it becomes necessary to translate the acceptance ratio, measured as a ratio of voltages at the receiver input terminals, back through the antenna transmission line and through the antenna into a ratio of local radiation fields at the antenna. Let the strengths of the desired and undesired fields at the antenna at the ith site in a given cell be $E_{di}(t)$ and $E_{ui}(t)$, respectively, and let the gains of the antenna in the directions from which these fields arrive be G_d and G_u, respectively. Then the corresponding signal voltages $V_{di}(t)$ and $V_{ui}(t)$, respectively, at the receiver input terminals are

$$V_{di}(t) = E_{di}(t) + G_d + K_d \tag{7a}$$

$$V_{ui}(t) = E_{ui}(t) + G_u + K_d \tag{7b}$$

when all quantities are expressed in decibels. K_d is the dipole constant of the antenna, representing the conversion factor between strength of the field at the antenna and the output voltage at its terminals. The ratio $R_i(t)$ of desired to undesired signal voltage is then

$$R_i(t) = E_{di}(t) - E_{ui}(t) + G_d - G_u. \tag{8}$$

Eq. (8) represents instantaneous conditions which vary with the passage of time. As was true in the earlier treatment, it is possible to deal with field strength levels exceeded for specified percentages of the time. Then the time-dependent quantities in (8) can be replaced by frequency functions. If $E_{di}(t)$ and $E_{ui}(t)$ are uncorrelated, that is, if knowledge of the time variation of $E_{di}(t)$ does not permit one to correctly predict the time variation of $E_{ui}(t)$, then the median value $A_i(50)$ of the voltage ratio $R_i(t)$ will be given by

$$A_i(50) = F_{di}'(50) - F_{ui}'(50) + G_d - G_u. \tag{9}$$

The assumption that $E_{di}(t)$ and $E_{ui}(t)$ are uncorrelated seems likely to be valid when the desired and undesired fields do not both arrive from nearly the same direction, thereby subjecting both fields to the same terrain effects. However, in the event that the arrival directions are nearly alike, it seems unlikely that lack of correlation can safely be assumed. In general, the symbol $A_i(T)$ designates that value of $R_i(t)$ which is exceeded for T per cent of a long period of time at the ith site.

When all of the other sites in a statistically representative sample of the sites in the given cell are considered, distributions $A(L, T)$, $F_d'(L_d, T_d)$, and $F_u'(L_u, T_u)$, are obtained, each having its own median and standard deviation. The medians, of course, are $A(50, 50)$, and $F_d'(50, 50)$, and $F_u'(50, 50)$, respectively. Since the sites are assumed to be uncorrelated, one can write the relation

$$A(50, 50) = F_d'(50, 50) - F_u'(50, 50) + G_d - G_u \tag{10}$$

by applying (9) to all of the sites in the sample and generating the cumulative distribution functions in the same manner described earlier for forming $F'(L, T)$ from a set of $F_i'(T)$ values.

By analogy with (2), one can also write

$$A(L, T) = A(50, 50) + n'(L) + M'(T), \tag{11}$$

in which $n'(L)$ and $M'(T)$ are proportional to the standard deviations of the distributions of $A(L, T)$ in L and T, respectively. Now a well-established theorem in statistics states that the standard deviation of a distribution consisting of the differences between corresponding values in a pair of uncorrelated distributions is equal to the square root of the sum of the squares of the standard deviations of the component distributions. The component distributions in the present case can be described by the relations

$$F_d'(L_d, T_d) = F_d'(50, 50) + k_d N(L_d) + M_d(T_d) \quad (12a)$$

$$F_u'(L_u, T_u) = F_u'(50, 50) + k_u N(L_u) + M_u(T_u) \quad (12b)$$

through comparison with (2). Thus, $n'(L)$ and $M'(T)$ in (11) are given by

$$n'(L) = N(L)\sqrt{k_d^2 + k_u^2} \quad (13a)$$

$$M'(T) = \sqrt{M_d(T)^2 + M_u(T)^2}. \quad (13b)$$

For present purposes, however, it will be convenient to leave $n'(L)$ unchanged. Substitution of (10) and (13b) into (11) yields

$$A(L, T) = F_d'(50, 50) - F_u'(50, 50) + G_d - G_u + n'(L) + \sqrt{M_d(T)^2 + M_u(T)^2} \quad (14)$$

This is the basic relation used in determining the limits for each grade of service under interference-limited conditions. $A(L, T)$ is the voltage ratio of desired signal to undesired signal which is exceeded at the input terminals of L per cent of the standard receivers in a given cell for at least T per cent of the time. Setting $T = 90$ per cent, setting $A(L, T)$ equal to the acceptance ratio for the prevailing type of interference, and solving (14) for L will yield the percentage of standard receiving plants in the given cell which will have service for at least 90 per cent of the time when one such plant is located at each site in a statistically representative sample of the population of uncorrelated sites in the cell. The parameters G_d and G_u may be regarded as constants throughout any given cell, values for $F_d'(50, 50)$ and $F_u'(50, 50)$ may be taken from standard curves such as those given by Allen,[5] and the constants $M_d(90)$ and $M_u(90)$ may be determined through the use of (3) in the manner described earlier.

In the special case in which the desired field can be regarded as independent of time, or when fading of the desired signal can be regarded as negligible in comparison with that of the undesired signal, $M_d(90)$ can be placed equal to zero in (14). The result is that

$$A(L, 90) = F_d'(50, 50) - F_u'(50, 50) + G_d - G_u + n'(L) + M_u(90). \quad (15)$$

Then, upon noting that

$$M_u(90) = - M_u(10) \quad (16)$$

because of the antisymmetry of the $M(T)$ functions about the $T = 50$ per cent line, as is evident in Fig. 7, one can use the relation

$$F_u'(50, 10) = F_u'(50, 50) + M_u(10) \quad (17)$$

which follows from (12b) to reduce (15) to

$$A(L, 90) = F_d'(50, 50) - F_u'(50, 10) + G_d - G_u + n'(L). \quad (18)$$

Eq. (18) is an approximation to (14) which can be used in place of it whenever the desired field can be regarded as having negligible time variation. Values for $F_u'(50, 10)$ can be taken from standard curves such as those given by Allen.[5]

This concludes the description of the location probability method. It has consisted of three principal parts: 1) Introduction of the concept of a cell and presentation of the basic cell statistics, involving the time-dependent field strength $E_i(t)$ and the time-invariant T per cent fields $F_i'(T)$ for all values of T at each site in the cell, and finally, the cumulative distributions $F'(L, T)$ for all of the sites in a statistically representative sample of the population of uncorrelated sites in the cell; 2) introduction of the concepts of a standard reference receiving plant, of a signal-to-noise acceptance ratio, of service, time availability of service, of location probability, and finally, description of the procedure for constructing a service map through the use of the $F'(50, 50)$ data and the standard cumulative distribution function $N(L)$; and 3) introduction of the concept of signal-to-interfering signal acceptance ratios, formation of the $A(L, T)$ functions and description of the procedures for relating them to the standard $F'(50, 50)$, $F'(50, 10)$, and $N(L)$ data, and description of the procedure for using these functions in the construction of service maps. A corresponding treatment will now be given for the acceptance ratio method.

ACCEPTANCE RATIO METHOD

The acceptance ratio method, like the location probability method, involves subdividing the area around the desired transmitting antenna into cells, the same criteria for specifying the size of a cell being applicable to both methods. The acceptance ratio method was conceived as a replacement for the location probability method on the ground that the available knowledge about the field distributions in space and time over typical terrain did not seem sufficiently precise to justify the use of such an elaborate mathematical framework as has been built up around the location probability method. To be more specific, it was considered that the procedures which had been provided for evaluating the quantities $F'(L, T)$ for desired and undesired fields rested on assumptions the validity of which could not readily be assessed on the basis of available data. As was pointed out earlier, the procedure requires that some specific form be assumed for the distribution of $F'(L, T)$ in both L and T. It is evident that whatever form of distribution is assumed, there will remain uncertainty regarding the basic suitability of the chosen form for the physical situation being considered. Even if the form is appropriate, that is, even if a normal distribution is a better choice then, say, a Rayleigh distribution, there still remains the problem of assigning numerical values to the constants which define the particular normal distribution to be used. Thus, numerical values must be assigned to k, $M(T_0)$, and $F'(50, 50)$ before (2) can be applied in the noise-limited case, and corresponding assignments must be made before the interference-limited case can be treated.

It is the objective of the acceptance ratio method to arrive at a specification of what grade of service is available within a given cell purely on the basis of $F'(50, 50)$ levels for the desired field and of $F'(50, T_0)$ levels for the dominant interfering field without recourse to assumptions concerning the way in which the $F'(L, T)$ functions vary with L and T. Thus, standard $F(50, 50)$ and $F(50, T_0)$ data would be required, but no use would be made of cumulative normal distribution functions. In order to realize this objective, the acceptance ratio method defines the limit for any given grade of service not in terms of the percentage of locations within a given cell at which a designated field strength level is exceeded for a specified percentage of the time, but simply in terms of whether the median field over the cell is large enough to override noise and interfering signals. The minimum acceptable desired field is determined by the noise characteristics of a specified standard reference receiving plant in the noise-limited case and by the strength of interfering signals arriving in the cell from various directions in the interference-limited case.

In addition to avoiding the use of assumptions concerning the form of the distribution of $F'(L, T)$ in L and T, the acceptance ratio method also seeks to provide for the demarkation of service grade limits solely on the basis of the new data developed during the period of operation of TASO. These data are of two principal kinds. One is the system of median curves and deviation formulas developed from the TASO data by Dr. LaGrone.[7] The other is a set of median curves and time-fading curves developed by the Bureau of Standards from a separate body of data. It has been proposed as part of the procedure for the acceptance ratio method that the field strengths obtained through the application of the TASO median curves and deviation formulas be regarded as $F'(50, 50)$ values for the desired field and that the Bureau of Standards curves be used to provide $F'(50, T_0)$ values for fields due to interfering stations when the latter are too remote from the cell in question to permit application of the LaGrone method.

Up until this point, discussion of the acceptance ratio method has been in general terms in order to outline the essential features of the philosophy on which it is based. Next to be presented is a detailed description of the method itself. Whereas an analysis in terms of the location probability method was ordinarily built around a single standard reference receiving plant so that only a single set of acceptance ratios would be encountered, the acceptance ratio method proposes to use a different reference receiving plant for each grade of service. TASO has recommended the use of three grades of service, to be designated Principal City, Urban, and Rural, and so the acceptance ratio method proposes the use of three reference receiving plants. The suggested characteristics of these plants would be derived from the TASO Panel 2 data on the characteristics of actual receiving plants observed in the field, and this would be done in a manner intended to establish for each grade of service a reference receiving plant whose characteristics would especially suit that plant for use in the prevailing environment and at the same time permit that plant to be assembled from a judiciously chosen but readily available selection of components. Thus, a receiver used as a standard reference receiver for rural service would be equipped to perform more satisfactorily with a weak signal from the desired station than would one designed as a standard receiver for principal-city service. This would mean that it would have higher sensitivity and lower noise factor. Similarly, it would be equipped with a high-gain antenna to which it would be connected by a transmission line which was laid out and maintained with more meticulous care than would be necessary or worthwhile in a principal-city installation. In the same way, this receiver would be provided with above-average capability for rejecting adjacent-channel and co-channel television signals because of the relatively high likelihood that such interfering signals might be present in sufficient strength to compete seriously with the desired signal.

It is thus to be considered that three standard receiving plants have been specified. Consider first the use of the principal-city standard receiving plant in arriving at the boundary contour determining the limit of the principal-city service area. It is assumed that the desired signal is sufficiently strong throughout the region receiving principal-city service so that any interfering signals which may be present can usually be safely ignored and the boundary fixed solely on the basis of the signal-to-noise acceptance ratio for the standard receiver. Since the noise factor and input noise level of the standard receiver are to be specified initially, and since a signal-to-noise acceptance ratio for principal-city viewers is also to be determined from subjective tests, the minimum acceptable level of desired signal for the standard receiver can be deduced. The $F'(50, 50)$ contour corresponding to this field strength level then becomes the boundary of the principal-city service area.

Next, consider location of the outer boundary of the urban service area. This, according to the acceptance ratio method, is to be the contour on one side of which the urban standard receiving plant gives satisfactory service and on the other side of which it does not. Service on the other side may fail to be satisfactory for either of two reasons. One is that the signal-to-noise ratio may be below the signal-to-noise acceptance ratio, and the other is that the signal-to-interference ratio may be below the signal-to-interference acceptance ratio. The desired contour is to be located by considering each type of signal degradation separately and then taking appropriate account of which influence is predominant in each individual cell. This will give rise to two separate contours. One contour will be that along which the $F'(50, 50)$ level of the desired signal is just high enough to permit the signal-to-noise acceptance ratio to be exceeded. This would then be the outer boundary of the urban service area if no interfering signals were present. The other contour will be that along which the $F'(50, 50)$ level of the desired signal and the $F'(50, T_0)$ level of the interfering signal are in such ratios that the ratios of the resulting signal voltages at the receiver input terminals just barely exceed the signal-to-interference acceptance ratio appropriate to the particular type of interfering signal under consideration. This ratio of field strength levels, of course, would need to be determined through consideration of the ability of the receiving antenna to discriminate against the interfering signal by virtue of the fact that the desired and the interfering signals generally arrive from different directions. The acceptance ratio method in the form most recently described[3] thus yields a contour for constant signal-to-interference voltage ratio at the receiver input terminals determined by a constantly varying ratio of desired-to-undesired signal field strengths at the receiver antenna. The variability of the latter ratio, of course, is attributable to the fact that the desired and interfering signals are arriving from directions with constantly varying angles of separation between them.

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[7] A. H. LaGrone, "Forecasting television service fields," this issue, p. 1009.

Returning to the two contours which would be found through the above procedures as the outer boundaries of areas receiving noise-limited and interference-limited service, respectively, it is next necessary to construct from these contours a single contour representing the unqualified outer boundary of urban service. This is to be done by constructing a new contour around the area which is simultaneously enclosed by *both* of the previous contours, so that both acceptance ratios will be exceeded in all cells enclosed by the new contour. In other words, the new contour will follow in every direction from the transmitting antenna whichever contour lies closer to the antenna. This procedure for establishing the location of the boundary for urban service will certainly be valid if the desired signal is constant in time. In the event that this constancy does not exist, the acceptance ratio method would propose to assume a tendency for positive and negative excursions in the fields to cancel each other, thereby permitting the median fields $F_d'(50, 50)$ and $F_u'(50, 50)$ to be used, where the subscripts d and u have the same meanings employed in describing the location probability method.

In the location of the boundary contour marking the outer limit of rural service, exactly the same procedure used in the case for urban service would be repeated, the standard rural receiving plant now being used as the basis for arriving at the appropriate acceptance ratios.

The following criticism has been leveled at the acceptance ratio method: As has been seen, the proposed method for fixing the boundary of an area receiving a given grade of service is such as to make the median field strength of desired signal on one side of the boundary just high enough to override noise and interference, while the median field on the other side is just short of being high enough. Some distance inside this boundary, that is, on the side toward the transmitter, the median field will evidently be appreciably greater than the value which yields a barely acceptable picture. Similarly, some distance outside this boundary the median field will be appreciably less than this minimum value. However, the acceptance ratio method provides no means for arriving at a number representing the percentage of time that an acceptable picture can be expected when the median field has any particular value. At the boundary itself, the picture will be acceptable only 50 per cent of the time. This, presumably, is too small a percentage of time to permit the service to be regarded as satisfactory. Some distance closer to the transmitter the percentage is higher, but the acceptance ratio method offers no means for determining how much higher. At some particular distance closer to the transmitter, the percentage will be just high enough to permit service to be regarded as barely satisfactory; but no means are provided for determining this distance, and hence, a contour cannot be constructed through such points. Such a contour, it would seem, should logically be used as a service boundary rather than that given by the acceptance ratio method. Defenders of the acceptance ratio method argue, on the other hand, that because of the uncertainty in the time dependence of the data which must be used with the location probability method, the location of iso-service contours for time availabilities other than 50 per cent is necessarily more subject to error than is that for those of 50 per cent.

SUMMARY AND CONCLUSION

To the casual reader, it will be plain at this point that use of the location probability method necessarily involves very extensive mathematical manipulation, and that relatively few mathematical operations are involved in using the acceptance ratio method. Presumably, he will wonder if the location probability method offers sufficient advantage over the acceptance ratio method to justify the use of the former in spite of the greater mathematical complexity of the operations involved. He might first recognize the obvious fact that no advantage will be gained at all if use of a more elaborate method does not lead to a result superior to that available from the acceptance ratio method. As has been seen, application of the location probability method involves the use of previously available experimental field strength data. If these data are not properly suited to the situation under consideration, then it would seem difficult to justify the additional mathematical labor involved. The Ad Hoc Committee itself, at the very time when it was developing the location probability method, recognized and called attention to the inadequacy of the data with which it had to work. For the next ten years after the development of the location probability method, users of this technique nevertheless had little choice but to use these admittedly inadequate data if they were to use the method at all. One of the most valuable results of the work of TASO was the generation of a new set of experimental data which promised to be more generally valid than were the data with which the Ad Hoc Committee had to work. It is not at all certain, however, that even these data are capable of providing as much information on the time and location variability of the fields as would be desirable for use with the location probability method. The great sensitivity of the location probability method to these time and location variability data is connected with (2). It will be recalled that this equation, in order to yield values for $F'(L, T)$, must have substituted into it suitable values for $N(L)$ and $M(T)$. It will be recalled that these two quantities were specified in (2) as representing cumulative normal distributions, but that they might under appropriate circumstances be replaced by cumulative distribution functions of other forms. One of the most important purposes which must be served by the standard data used with the location probability method is that of providing for the determination of the appropriate forms for these functions.

On the basis of these considerations, it might appear that the acceptance ratio method ought to be used in preference to the location probability method. This, however, is not necessarily a safe conclusion in view of the fact that, inadequate as the standard data are, they may still provide with the probability location method a high enough degree of precision to offset the best accuracy that the acceptance ratio method can offer.

Another very strong argument is available for the location probability method. It has been seen that this method provides measures of the percentage of locations in a given cell which are able to obtain satisfactory service. On the basis of such a number in combination with data on the population density in a cell, it becomes readily possible to calculate the number of people who have service in a given cell for any given value of L. In the case of the acceptance ratio method, on the other hand, it is possible to arrive at a numerical measure for the number of people per unit area capable of receiving satisfactory service only on the boundary contours between regions having different grades of service, since only along these contours can a value be found for L.

In conclusion, it seems that neither method is always clearly superior to the other. In the long run, it seems certain that the location probability method must prove superior, but this can happen only after suitable experimental data are available for use in conjunction with it. In the meantime, when determinations of the types given by these methods are to be made, it seems appropriate that both techniques be considered.

The Television System from the Allocation Engineering Point of View*

ROBERT M. BOWIE†

Summary—**Television allocation is technically dependent upon the properties of the television system comprising, in sequence, the transmitter plant, the propagation path, the receiver plant and the observer. Performance is limited either by receiver noise or by noise and undesired signals entering by way of the receiver antenna. Analysis of this system and its components has led to criteria by means of which service may be defined. These criteria have been incorporated in a procedure for producing maps portraying selected isoservice contours applicable as defining boundaries of the several grades of service. Precision of portrayal is limited essentially by the uncertainty of measurement or prediction of propagation which has led to the use of quasistatistical methods of treatment. Some resulting limitations are pointed out.**

THE United States has for some time been confronted with an unresolved television allocation problem arising, not from the lack of assignable spectrum, but rather from significant differences in signal propagation and equipment performance over the wide frequency spectrum assigned to television.

These differences are not astonishing when one recalls that the assigned spectrum extends over almost four octaves.

This great breadth of spectrum is increased considerably over that required to accommodate the 82 channels by the assignment of gaps between the low and high VHF and between the VHF and the UHF. These gaps are equivalent to 55 channels.

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* Original manuscript received by the IRE, February 12, 1960.

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Experience during the decade since the UHF band was added to television has demonstrated that the differences in propagation over the broad television spectrum cannot be disregarded, and that ten years have not been sufficient time to reduce the disparity in equipment performance over this spectrum appreciably. It has been pointed out that even with a substantial improvement in performance of UHF transmitters and receivers relative to VHF equipment, such as by the use of parametric amplifiers in the receiver, there will remain at least a 15-db advantage to the VHF in fringe-area performance because of propagation differences alone, while phase anomalies in the UHF wavefront at the receiver antenna site appear likely to preclude the use of UHF antennas having an effective aperture or signal-gathering ability equal to that of VHF antennas. It has become evident, however, that television service must be economically competitive in any one locality. A number of technical approaches to the resolution of this problem are now in various stages of study, evaluation or use, although as yet the FCC has not completed its study and finalized its choice among them. They are listed:

1) "Deintermixing" of VHF and UHF assignments.
2) A two-class allocation plan involving limited broad-area, high-power VHF stations interspersed with less restricted local UHF stations.
3) Shifting all television to UHF.
4) Shifting all television to VHF and
    a) using close-packed allocation principles [1] under which a station's service area would be limited by interference from its neighbor, and not by receiver noise;
    b) obtaining a larger VHF spectrum by trading UHF spectrum to the military.
5) Multicasting, particularly in the UHF, wherein more than one transmitter at the same, or possibly at another frequency, is operated by one station using closed-link interconnection.
6) Rebroadcasting (regardless of ownership of rebroadcast equipment)
    a) at some frequency (boosters);
    b) at another frequency (translators).
7) Employing very-precise-carrier frequency control, particularly with the close-packed allocation plan.
8) The using of directional transmitter antennas, such as with multicasting.
9) Employing cross-polarization of transmissions such as with close-packed allocation, multicasting and boosters.
10) Increasing transmitter power—particularly at UHF.
11) Increasing transmitter antenna heights—particularly at UHF.
12) Reducing aural-to-visual transmitter power ratio,
    a) by increasing visual power;
    b) by decreasing aural power, particularly with close-packed allocations.
13) Improving receiving plant performance in the UHF such as with parametric amplifiers and lower-loss lead-in lines. (The performance of high-quality VHF receiver plants is probably a practical limit here which leaves at least some 15-db poorer fringe area propagation in the UHF relative to the VHF.)
14) Improving receiver plant discrimination against television interference, particularly when close-packed allocation is extensively used, both in UHF and VHF.
15) Satellite transmissions or reflections (not imminent).

It is interesting to note in the above listing that some nine items are concerned with propagation; four are essentially instrumental and two involve both. This points up clearly the critical importance of propagation in the preparation of any sound television allocation plan. The relationship of this factor to the others constituting a television service can best be seen by reference to the Systems Concept Chart of Fig. 1.

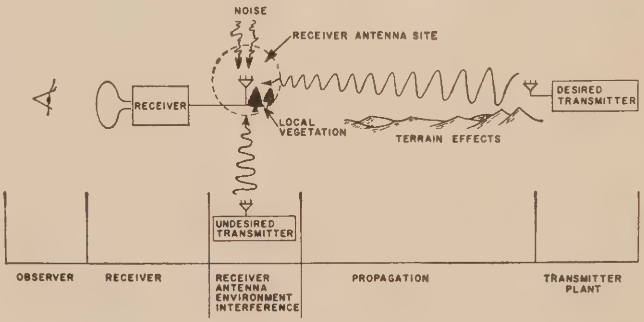


Fig. 1—System concept chart.

I. Systems Concept

The Systems Concept Chart [2] was originally developed by TASO Panel 5, but was tacitly employed earlier by the Ad Hoc Committee [3] in its reports of 1949 and 1950, and by the FCC [4] in its Third and Sixth Reports.

The equipment and propagation paths by means of which a television program is conveyed from a studio into a viewer's consciousness can be regarded, for the desired signal, as a sequential system. Furthermore, with the exception of receiver noise, the interference and undesired signals all enter this sequence at essentially one point, the receiver antenna. The sequentiality with interference entering essentially at one point considerably simplifies the analysis of the system. The process of analysis is not unlike that for a transmission line in which the transfer characteristics of the line elements are known. One can start at either end of the system, and using the characteristics of each element in sequence, can compute at each step the characteristics for the system as seen looking back along the path of computation.

If one starts with the observer, he needs to know the human reaction to varying degrees of picture degradation produced by each of the various types of interference to be expected. This information has been obtained in a consistent manner for all of the major types of interference by TASO Panel 6 (Levels of Picture Quality). As an example of its findings, a curve providing this kind of information for lower adjacent-channel interference is shown in Fig. 2. There are, of course, similar curves for the other forms of interference.

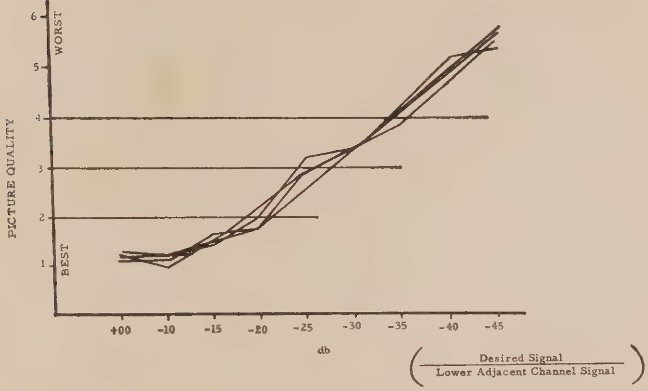


Fig. 2—Graph of picture quality vs ratio of desired signal to lower adjacent-channel interference (from report of Panel 6).

The ordinate, picture quality, is a statistically obtained measure of human satisfaction, while the desired-signal-to-lower-adjacent-channel-signal ratio is expressed in db. Similar curves have been prepared for upper adjacent channel, random noise and various forms of co-channel interferences. In all cases the ratios apply at the input terminals of the receivers used in the tests. Thus, to transform the curves to apply at the receiver antenna location, it is necessary only to have available the characteristics of the lead-in line and the antenna. The latter must include the directional properties of the antenna, because the desired and undesired stations will usually have different bearings from the receiver location.

Actually, it is not necessary for allocation purposes to transform each curve in its entirety, but merely to transform certain critical or limiting numbers to the antenna location. If the FCC were to specify the three grades of television service recommended by Committee 5.3 of TASO Panel 5—namely, Principal City, Urban, and Rural—then the Commission would first need to select the lower limit of picture quality applicable to each grade of service. For illustrative purposes here, these limits have been chosen to be as 2, 3 and 4, respectively, on the picture quality scale. If one now considers the case of lower adjacent channel interference, the undesired signal cannot exceed the desired one by more than 20, 26 and 34 db, respectively, for the three grades of service. These values have been read from the curve of Fig. 2. The reason for permitting the undesired lower adjacent-channel signal to be much stronger than the desired signal for an acceptable picture is that television receivers have strong rejection against lower adjacent channel signals built into them. Using the method just described, one can develop three limiting ratios corresponding to the three grades of service for each of the various types of interference for which the Commission wishes to set limits. These limiting ratios, expressed in db, could be tabulated in the following manner where the blank spaces would be filled in with figures applicable at the receiver input for the qualities of picture specified by the FCC.

	Principal City	Urban	Rural
Upper adjacent channel			
Lower adjacent channel			
Co-channel			
Image			
External random noise			

To transform these limiting ratios as tabulated to apply at the receiver antenna site, it is necessary to know, for each grade of service, what quality of typical receiver plant the Commission wishes to specify. When the Commission specifies a typical receiver plant for a grade of service, it would, in essence, be specifying the transfer characteristics of the antenna, lead line [5] and receiver. In the TASO Report [6], such typical transfer characteristics have been selected for illustrative purposes and the computations have been carried out yielding, for the lower adjacent-channel case, interference ratios applicable at the receiver antenna site. The resulting ratios are 12, 32 and 59 db, respectively. These, then, are the factors expressed as db ratios by which the lower adjacent channel signal may exceed the desired signal for a just acceptable picture as defined earlier. These db ratios at the antenna location then become "the critical numbers" for television allocations.

To carry out the calculations, it was necessary to assume that the FCC had selected fixed values for the antenna's discrimination against undesired signals arising from the directional characteristics of the antenna. Otherwise, different sets of ratios would apply in different directions about the receiver antenna. Later in this report, that simplification is removed.

The "transfer" characteristics of the receiver plant include such receiver and antenna characteristics as the adjacent-channel rejection ratios, image rejection, receiver noise factor, lead-line loss and antenna aperture or λ factor and gain. In general, the antenna characteristics are functions of both azimuth angle and channel number. To assist the FCC in its selection of typical receiver plant characteristics, TASO Panel 2 compiled comprehensive tabulations based upon extensive surveys of sets and antennas in manufacture [6] in 1958.

II. CRITICAL NUMBERS

By the process just described, it is possible for the FCC to arrive at a set of critical numbers for each grade of service and to specify, in terms of field strength ratios [7] at the receiver antenna location, what signal is deemed necessary to render a particular grade of service. The critical numbers now become the terms in which to express the three limiting isoservice contours that define the boundaries of the three grades of service. More will be said of these contours later.

III. PREDICTION OF PROPAGATION

The most elusive and probably, therefore, the most critical task of TASO has been to provide means for predicting, with useful accuracy, where and how much television service will be rendered. The critical numbers just described provide means for defining service in terms of field requirements at a site. What is needed beyond this are means for predicting the propagation of the desired and the undesired signals from their respective transmitters to arbitrary receiver sites in the service area. Unfortunately, this cannot be done with meaningful accuracy for any one receiver site because propagation is subject to variation with frequency, terrain, gradient of the index of refraction of the atmosphere, the time of day and year, and the vegetation in the vicinity of the receiving antenna. Theoretical formulas exist for propagation over a smooth earth of arbitrary conductivity as a function of frequency, taking into account different gradients of the atmospheric index of refraction. However, basic theory and mathematics for coping adequately with irregular terrain and local clutter do not exist. It has been found necessary, therefore, to treat propagation on a statistical basis for both time and location. This means that one cannot predict precisely what desired and undesired fields will be laid down at a receiver antenna site, but rather can predict the probabilities of laying down these fields. Diurnal variations in field strength at a point near or beyond the radio horizon may, for example, be of the order of 15 to 20 db, while seasonal variations are of the same order. In like manner, the fields experienced at various locations in a given locality can vary by even greater amounts, particularly if the terrain is rough. It is customary to denote by $F'(L, T)$ that field which can be expected to be exceeded in L per cent of locations in a locality for T per cent of the time by a specified transmitter plant. For example the $F'(50, 50)$ field will be exceeded in half of the randomly selected receiver sites in the locality for half of the time. The term "locality" is somewhat vague for lack of any clear-cut criterion for its size. It must be large enough so that readings are not related to each other as they might be if taken on adjacent house tops, yet it must not be so large as to contain excessive variations with distance from the transmitter or with major changes in terrain. The principal dimensions of such a locality are of the order of a few miles to a few tens of miles. More will be said of this later in discussing portrayal of coverage. Suffice it to say here that this vagueness does not destroy the usefulness of the concept and provides a very necessary smoothing factor in mapping the fields about a transmitter for allocation or assignment purposes. Allocation, or even assignment, is a "broad-brush" type of task from which local detail must be omitted in the interest of broad comprehension and decision.

Since $F'(L, T)$ fields such as $F'(50, 50)$ fields cannot be calculated by purely theoretical means, various methods of obtaining them empirically have been developed. Probably the best known of these are the 1952 $F(50, 50)$ curves [8] contained in the Rules and Regulations of the Commission (Section 3699 of these Rules). They were obtained by averaging available propagation data for all parts of the country at all times of the year; hence, they are too general for the study of specific station assignments. They have been recommended as Type I curves by Committee 5.4 of TASO Panel 5, as have also those of the FCC-TRR Report No. 2.4.16.

Committee 5.4 foresaw [9] need for three successively more exact and detailed methods for predicting television service field strengths; these were designated Type I, II and III.

Briefly, a Type-I curve is an average empirical propagation curve to be applied on a country-wide basis for broad or preliminary purposes. A Type-II curve would take into account average large area effects such as terrain roughness and meteorology and is believed suitable for allocations and assignments purposes except in rugged terrain. A Type-III curve would permit the prediction of field strength in relatively small areas for specific conditions of terrain and meteorology. It would be useful for allocation and assignments in rugged terrain and for detail studies of assignments in rolling terrain.

A Type-II method or curve should be capable of yielding $F'(50, 50)$ fields on a locality basis throughout the service area of the transmitter. One such method was developed by Howard T. Head [10] and submitted to Committee 5.4. It is of the type in which empirical corrections are made to theoretical propagation curves based on a standard smooth-earth formula. Standard atmosphere is also assumed. A suitable number of radii from the transmitter are laid out on a large-scale contour map and elevations are read at exactly two-mile intervals on each radius. These elevations are plotted on Cartesian coordinates, as shown in Fig. 3, and a best-fit "least squares" straight line is drawn. The intercept on the ordinate establishes the effective antenna height for that radius, while the rms deviation of the points from the line in feet yields the roughness factor R. By analysis of the field data gathered by Panel 4, it has been established empirically that the loss in db relative to the smooth-earth fields is approximately $3.6\sqrt{R/\lambda}$, where λ is the free-space wavelength. This empirical relation was found to hold for both VHF and UHF,

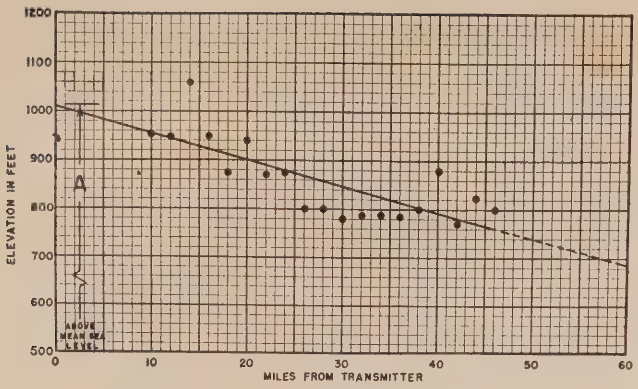


Fig. 3—Elevation sample points and least squares fit.

though better results at UHF can be obtained by also taking forestation [11] into account. The resulting empirical equation involving the percentage of forestation P_f is

$$\text{Loss (db)} = \frac{30P_f + 3.6(100 - P_f)\sqrt{R/\lambda}}{100}.$$

The method has the advantage of relative simplicity, but provides no character along a radius other than a uniformly degraded smooth-earth curve. Committee 5.4 has recommended consideration of this method for allocation purposes, based on further test to gain experience.

Committee 5.4 has recommended for consideration as a Type-III method that developed by Prof. A. H. LaGrone [12] of the University of Texas under contract to TASO. His method provides for the making of empirical corrections to theoretical smooth-earth propagation curves, modified, however, to account for the effect of local clutter at the receiver site. The smooth-earth calculations are made by using local Weather Bureau average data for the gradient of the atmosphere's index of refraction; this gradient affects the effective radius of the earth.

During the development of the empirical formula, it was noted that as the terrain being studied approached the ideal smooth-earth, there remained an unaccounted degradation which appeared to bear some relation to the level of forestation or local clutter at the receiver site. By the preceding method, Dr. LaGrone estimated this form of degradation to be −1 db for the lower VHF, −4 db for the upper VHF and −22 db for the UHF. This modification to the smooth-earth formula is applied before computing the further degradation in the field at a point due to the effect of the terrain intervening between the point and the transmitter. The determination of field strength is made for a point in the service area of the transmitter by drawing an accurate radial profile through the point and applying the following empirical formula to find the degradation from the modified smooth-earth curve:

$$\begin{aligned}\text{Loss (db)} &= C\left[-\left|h_1 - h_2\right|^{\frac{1}{2}}(\exp - d_{1r}) - \left|h_2 - h_3\right|^{\frac{1}{2}}(\exp - d_{2r})\right.\\ &\qquad \left. + \left|h_3 - h_r\right|^{\frac{1}{2}}(\exp - d_{3r})\right]\end{aligned}$$

where

h_1, h_2, h_3 and h_r are elevations in feet above mean sea level,

d_{1r}, d_{2r}, and d_{3r} are distances in miles as defined in Fig. 4,

$C \cong 1.6$ for VHF, and

$C \cong 2.2$ for UHF.

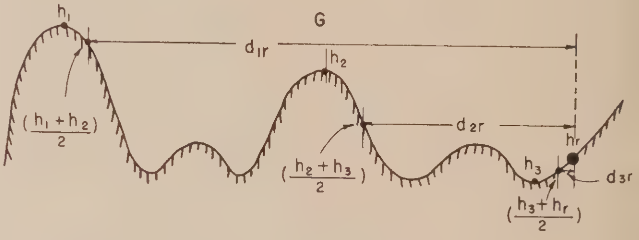


Fig. 4—Sample cases of terrain (measure height in feet and distance in miles).

The second part of Reference [12] contains additional typical hill configurations together with appropriate modifications of the empirical formula. The presentation here is not intended to be complete and the reader is commended to the reference for full information.

Unfortunately, this method has been derived using only about half of the Panel 4 data. However, cross-correlations as high as 0.8 have been obtained in making comparisons of computed fields with Panel 4 data for rough terrain. Further experience with this method is proposed before its full adoption for allocation and assignment purposes. It should be noted that this method yields more specific and detailed field information than the method described earlier, but at the cost of greater computational effort.

IV. Specification of Service

From the standpoint of the receiver plant, service can be defined, for the purpose of this report, as the transform of the level of picture quality into the corresponding desired field strength and interference ratios at the receiver antenna site. The transformation is brought about through the use of the characteristic of the receiver plant and, hence, service is explicitly dependent upon a stipulated receiver plant. It is necessary at this point to give special attention to the receiver antenna pattern, since this is one of the essential characteristics of the receiver plant. If it is assumed that the antenna maximum is directed toward the desired signal, the relative bearing of an undesired signal must be considered in computing the corresponding interference ratio. Thus, each interference ratio is a vector quantity and could take the form of a polar plot.

If a particular level of picture quality is now set as the limit for a given grade of service such as Urban, then the corresponding limiting service required by the receiver antenna can be expressed in terms of a set of criteria. This set will include a value of desired signal strength and values for each of the interference ratios such as co-channel, lower adjacent channel, image and so on.

At this stage, the location of the receiver site relative to the desired and undesired transmitter is arbitrary; hence, as before, each criterion (except desired signal) is really a polar plot. However, for ease of manipulation, values for several selected directions could be tabulated as illustrated below.

	Principal City				Urban				Rural			
	0°	60°	120°	180°	0°	60°	120°	180°	0°	60°	120°	180°
Desired field strength		╳	╳	╳		╳	╳	╳		╳	╳	╳
Lower adjacent-channel interference ratio												
Upper adjacent-channel interference ratio												
Co-channel interference ratio												
Etc.												

Thus far, service has been considered only under steady-state conditions. Since these do not prevail in practice, the statistical nature of the service rendered at a receiver site must be introduced. It is obvious that each field at the receiver antenna site may vary quite independently in such a manner that the actual interference ratios experienced in the locality of the receiver site will vary both with time and from site to site in the locality. It is difficult to give quantitative figures for the effect of such variations upon service because they are dependent upon viewer reaction to both picture quality fluctuations and inhomogeneity of receiving conditions in a locality. To obtain meaningful figures here, one would need to conduct statistical viewer tests on the effects of various types of fading and upon the sociological effect of inferior and superior sites in the locality. Lacking these, one might make a beginning by stating that for mild excursions from the mean in both time and location, the effect of positive excursions would be substantially offset by negative ones. Under this condition, the desired field and the interfering field whose quotient yields the corresponding interference ratio could be replaced directly by the median, or $F_d'(50, 50)$ and $F_u'(50, 50)$ fields where the subscripts d and u denote desired and undesired signal [13], respectively.

The extension of the principle that the effects of small excursions about a mean are self-compensating to the case of wide excursions is fraught with some uncertainty. However, because of the lack of data on which to base a better choice, there seems to be no obviously superior alternative. Proceeding then with the use of median fields, the limit of a grade of service such as Urban would consist of a set of criteria as before, but with the median field values replacing the former steady-state fields.

It has been the practice of the FCC to express the limits of service in terms of field probabilities other than 50 per cent. For example, Grade A service requires that pictures of acceptable quality be obtained in the best 70 per cent of sites in a locality for at least 90 per cent of the time. It is clear, of course, that if the time and location distribution functions for the various desired and undesired fields involved are known, one can always find from the median field values other sets of field values that will yield the desired quality of picture for other percentages of locations and times. This is essentially what is done in the location probability method as employed by the Commission [14]. For a mathematical treatment of this subject, the reader is referred to the companion paper by D. C. Livingston [15].

Two disadvantages of using nonmedian field values are that they have a greater uncertainty than the 50-per cent values and the labor of computation is greater. Probably the major attraction lies in an intuitive feeling that the specification of service in terms of field probabilities higher than 50 per cent is more realistic.

It has been the practice with the location probability method to employ a single specified receiver plant for both currently specified grades of service and to distinguish between them by requiring a higher level of location probability for the better grade of service. Thus, for Grade A service, an acceptable picture must be available in the best 70 per cent of locations for at least 90 per cent of the time while for Grade B, an acceptable picture is to be expected in only the best 50 per cent of locations for 90 per cent of the time. However, the location probability method, in its broadest interpretation such as evolved during the life of TASO, need not be limited to a single specified receiver plant for all grades of service [16].

Also during the life of TASO, a simplifying modification of the location probability method of specifying the limit of service was evolved which became known as the acceptance ratio method. It employs median-service fields and also different standard receiver plant for each grade of service.

In both methods, for lack of better data, it has been found expedient to employ the field data as though having a 50-per cent time probability. The usual practice is to take data during daytime hours only and at such times of the year as meet measurement schedules; hence, such data are not truly time-median values. Further, it is recommended that field strength measurements be made along roads using a 30-foot antenna height. Hence, the field data contain a "road" bias as well as the "temporal" bias. These same biases exist in the Head and LaGrone methods of field prediction, as both are empirically dependent on the data of Panel 4 which were taken in this manner. It was felt by Committee 4.1 of TASO Panel 4 that steps should be taken to reduce these sources of uncertainty [18].

Regardless of whether the location probability or the acceptance ratio method were used, the set of "critical numbers" employed in specifying the limits of the grades of service would continue to look like the tabulation given earlier in Section IV, but with the spaces filled in with db ratios that take into account the statistical nature of television service.

V. ISOSERVICE CONTOUR AND PORTRAYAL OF COVERAGE

The last technical step in the preparation of data for use in allocation or assignment is the production of a map (or maps) of the area about a transmitter showing where service is available and how much. The map should be reasonably unique so that maps prepared by different engineers from the same basic data will not exhibit major differences. Such a map must be capable of showing two or more grades of service and must be fine grained enough to show the relative coverage in different directions from the transmitter and in different areas. Finally, it must be possible to draw the map in a straightforward manner with reasonable effort by means of suitable propagation curves and data, and to confirm the predicted areas from a reasonable number of field-strength measurements taken in an appropriate manner.

Though there was not evinced in TASO a full unanimity regarding a suitable method of portrayal, there was a consensus favoring a method of the type about to be described. It is believed that this method satisfies the criteria just set forth which have been derived from those in the Report of Committee 5.3 [19].

It appears desirable and proper that the limit of a grade of service be an isoservice contour. Since it is recommended that there be three grades of service, there would then be three corresponding outer limiting isoservice contours. Disregarding minor enclaves and exclaves, it is evident that the grades of service will lie one outside the other with the Principal City grade at the center. About the latter will be the Urban grade as an annular ring and beyond that another annular ring representing the Rural service area. The inner boundary of each such annular service area will be set by the outer limit of the next higher grade of service while the outer limiting isoservice contour will be established by the criteria for the grade of service directly involved.

Since service, as previously defined, depends on the specified receiver plant, then, if a different receiver plant were specified for each of the three grades of service recommended by TASO, there would be three sets of limiting isoservice contours. In such a set, there would be a separate isoservice contour for the desired signal and for each form of interference. A simplified set of such isoservice contour, using only three contours, is shown in Fig. 5.

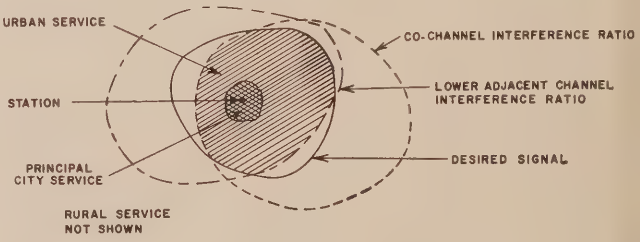


Fig. 5—Examples of the manner in which a service area is bounded by overlapping contours of constant desired signal strength and interference ratios.

In general, these various limiting isoservice contours would not be expected to agree. The service area as shown cross-hatched in Fig. 5 is that area which is within all of the contours, excluding, however, the areas of the higher grades of service. In Fig. 5 the Principal City service area is so excluded.

The drawing of any contour on a map first requires the plotting of points having the appropriate value for that contour. This is to be done for the limiting isoservice contour associated with each form of interference. Because of the great variability in individual field strength measurements and the necessity to hold down the labor required to obtain the necessary data, Committee 4.1 of TASO Panel 4 has proposed the following method for obtaining the points for plotting [20].

Draw on the map of the area about the transmitter a series of concentric circles ranging in radius from five to ten miles less than the expected Principal City contour to slightly beyond the expected Rural contour. There should not be less than three or more than five such circles, and their radii should be chosen in 10- to 15-mile steps. Divide the area about the transmitter into eight 45° sectors. This plan is shown for a typical VHF station in Fig. 6. The total number of data points should be equal to about 80 times the number of circles, but distributed approximately as the square roots of the radii of the various circles. Note on Fig. 6 that these radii and circles constitute the center lines of cells such as the one cross-hatched in the figure. A cell can now be defined as a locality with definite boundaries. The computations proceed on a cell basis.

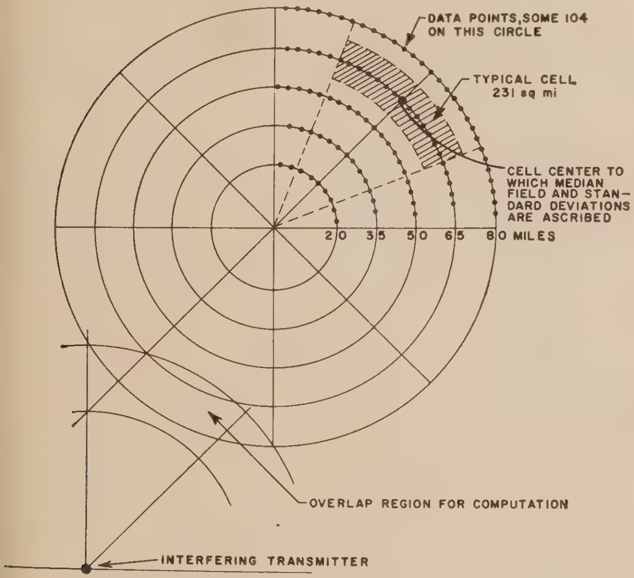

DATA POINTS,SOME 104 ON THIS CIRCLE
TYPICAL CELL 231 sq mi
CELL CENTER TO WHICH MEDIAN FIELD AND STANDARD DEVIATIONS ARE ASCRIBED
20
35
50
65
80 MILES
OVERLAP REGION FOR COMPUTATION
INTERFERING TRANSMITTER

Fig. 6—The cell layout about a tramsmitter.

Up to this point, it has not been made clear whether the field strength data at the points on the circles are to be computed or measured. The plan was drawn for field measurements, but with some modifications to line up the data points along radials, computation could be used conveniently. The median field is then determined for each cell and the median value ascribed to the center point of the cell. The standard deviation is also determined for the cell and ascribed to its center. The procedure as described is intended to apply particularly for the service field. However, with a little care, similar but intersecting circles could be drawn about nearby interfering transmitters as shown in Fig. 6 and the interfering fields computed (or measured) for the overlapping, interfering cells. If, however, the interfering transmitter is remote enough to be in the tropospheric transmission range, resort may be had to the tropospheric propagation curves provided to Committee 4.2 of TASO Panel 4 by The Central Propagation Laboratory of the Bureau of Standards at Boulder, Colorado [21].

From this procedure there would result a full set of desired and interfering field values ascribed to the center of each cell about the desired transmitter. Sets of interference ratios could then be computed at each cell center. However, these interference ratios would generally not be exactly the desired ones for the limiting isoservice contours. This is because of the coarseness of the cell structure. The desired points for the various interference ratios can then be located along each 45° radial by linear interpolation from the values at the adjacent cell centers. The particular limiting isoservice contours associated with various interference ratios can then be sketched.

VI. Selection of "Critical Numbers" for Limit Contours

It is believed that valuable information can be gained from the observations of TASO Panel 3 that would be useful in the selection of "critical numbers" for specifying the limiting isoservice contours. Panel 3 observed [17] that as one recedes from the transmitter through the service area, the quality of the receiver plant tends to improve in such a manner that the received picture quality is substantially constant out to the point at which it becomes economically prohibitive to make further improvements. One of the curves prepared from the Panel 3 data is reproduced here as Fig. 7. Examination of this curve and the others in Reference [17] shows a substantially constant level of picture quality, with only the expected statistical spread, out to the point at which the curve appears to break downward. This is the point at which further receiver plant improvement becomes uneconomical. It would seem logical, therefore, to select a single level of picture quality for the first two grades of service. The evidence from the findings of Panel 3 indicate that public reaction would place the limit at $2\frac{1}{2}$ or 3.

It is interesting, also, to examine the data that define the break downward in the level of picture quality vs distance curves. As Panel 3 has pointed out in its report (TASO Rept., p. 221), this break appears to come, for the lower VHF, at the point at which the field strength for the desired signal drops to 40–45 dbu. For the upper VHF the figure appears to be 50–55 dbu. These figures appear worthy of consideration in the setting of limits of service for cases in which the limit is expected to be set by receiver noise.

For the outer or Rural Grade of service, one is operating on the declining portion of the curve. From Fig. 8, taken from page 208 of the report of Panel 3, it is evident that the density of points falls off with decreasing level of picture quality at a value of about 4.5, though the drop in density is not sharp. Examination of the Panel 3 curves (TASO Report, pp. 208–215) shows that for the low VHF the corresponding field strength to

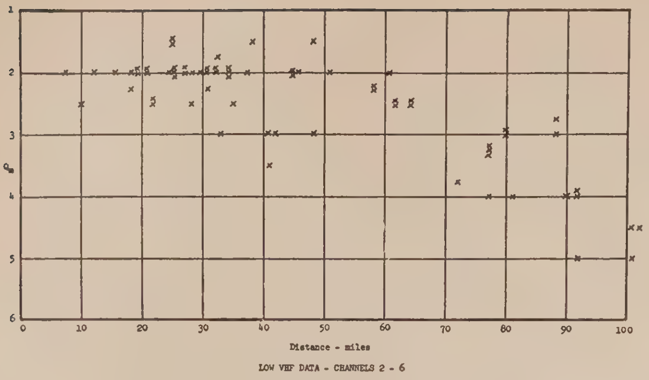


Fig. 7—The VHF data—Channel 2–6.

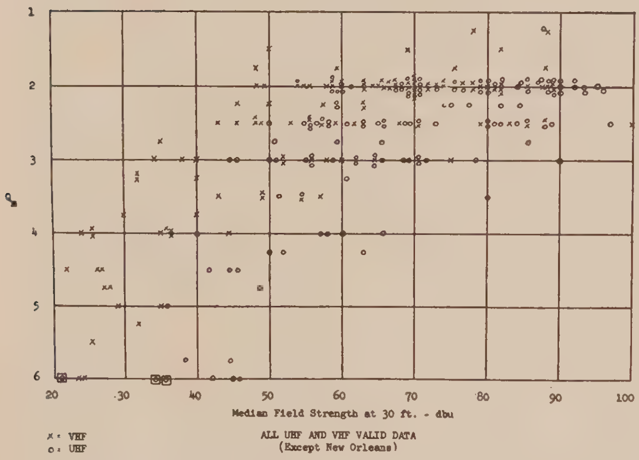


Fig. 8—All UHF-VHF valid data (except New Orleans).

be about 25 dbu. At the high VHF it is about 30 dbu and for the UHF about 50 dbu. These figures probably chiefly represent reception limited by receiver noise, as the observations were made in the daytime when television interference tends to be at a minimum; hence, they would be of interest in selecting the critical number to define the outer limiting contour for desired signal strength.

Concluding Remarks

Though TASO has contributed extensively to the available body of data on television service and to the orderly understanding of the mechanisms of allocation, there remain points on which continued elucidation and improvement are needed. Some of these are listed here to stimulate further attention.

1) It has been pointed out that temporal biases exist in the recommended method of taking data and in the two proposed formulas for field prediction. Some worthwhile correction could probably be made to new field strength data obtained by the method of Committee 4.1 if note were taken of the time of day and year for each measurement and if generalized correction curves were worked out to show how much the field at various times of day and year can be expected to vary from the all-time mean. It is possible, also, that correction factors could be worked out for the field computation methods of LaGrone and Head, since they are based on Panel 4 data.

2) The use of interference field data from the curves of Committee 4.2 in computing interference ratios introduces another minor source of error because the data were taken too well. In general, the receiving sites were selected to be quite free of local clutter of the type encountered in most television reception locations. No doubt degradation factors can be worked out for frequency, possibly for topographical roughness and for forestation. It should be borne in mind, also, that these are all-day, all-year medians and their use with uncorrected daytime, seasonal field data introduces some error.

3) The "road-bias" problem remains unresolved. Either the median or $F'(70, 90)$ field strength value computed for a cell really represents the probability of achieving the specified field or better in road measurements, and not necessarily in randomly located receiver plants of the specified quality. Some satisfaction might be gained by examining the data on the level of picture quality vs field strength compiled by Panel 3 (TASO Rept. [6], pp. 208–215). That Panel found, however, that detailed correlations between roadside measurements and adjacent home observations could not be made. Furthermore, the tendency for the receiver plant improvement to compensate for field strength degradation would mask any correlation, since grades of receiver plants were not reported. Additional study needs to be given to this matter.

4) It is recognized that, in general, limits of areas of service will be somewhat distorted circles about the transmitter. Since each limit is actually a selected isoservice contour, this means that the direction of maximum gradient or rate of change of service is perpendicular to this contour, and, hence, is chiefly radial in direction. Accordingly, to be able to set the limit contours most accurately, one needs to have the greater knowledge about the radial, rather than the circumferential, field variation. Presently, however, items of data are planned to be three times as dense circumferentially as radially. Further, for UHF stations, as presently proposed, there could be as few as three data circles about the transmitter to set three service limit contours. This comment points up

the need for some further study of means for improving radial detail, even at the expense of circumferential if necessary. Study is suggested in the following three areas: a) a Type-II method of field prediction having radial variations responsive to terrain; b) the laying out of the cell structure about the transmitter so as to improve radial detail; c) the development of a procedure for taking proof-of-performance field data yielding greater radial detail.

5) The evaluation of the effect of local clutter near the receiver antenna site has been recognized as needing serious attention. Some definite progress on the effect of forestation has been made, but the work needs extension, and it should be pointed out that little is yet understood about the effects of such obstructions as power lines and adjacent buildings.

It is believed that the work of TASO has provided a consistent over-all approach to the technical problems of allocation and station assignment. The salient features of this approach are outlined in the following:

1) The first consistent set of human reaction curves was evolved. These relate picture quality to signal degradation resulting from each of the important forms of interference such that meaningful correlations can now be drawn among the effects of the various forms of interference. Thus, it is now possible to state, for example, the level of lower adjacent channel interfering signal that is equivalent to a stated level of co-channel interfering signal. This is essential in drawing isoservice contours.
2) Sets of television service field data taken from extensive field measurement made in a consistent manner for the entire television spectrum and for the various forms of terrain throughout the United States were compiled. These data have served, and may continue to serve, as the basis of new empirical procedures for predicting service fields.
3) Two partially empirical procedures of service field predictions, applicable in all parts of the country, were developed and recommended for further study.
4) The pertinent characteristics of television receiver plants in production in 1958, from which typical receiver plant specifications may be drawn for allocation purposes, were analyzed and tabulated.
5) Transmitter plant characteristics and costs suitable for use in determining the economic feasibility of various allocation plans were compiled.
6) A philosophy of, and procedures for, the specification of service, the prediction of performance and the portrayal of coverage were set forth.

Through the deliberation of TASO, there have been evolved a broader interpretation of the location probability method of specifying service and a simplified form of this method. The latter reduces the labor of calculation with no significant reduction in the meaningfulness of the results.

BIBLIOGRAPHY

[1] Reference [6], p. 362—referred to as "Interference Limited," Principles of Allocation.
[2] R. M. Bowie, "Systems approach to the determination of television coverage," *Elec. Engrg.*, vol. 77, pp. 129–132; February, 1958.
[3] Ad Hoc Committee for the Evaluation of the Radio Propagation Factors Concerning the Television and Frequency Modulation Broadcast Service in the Frequency Range Between 50 and 250 mc, vol. I, FCC Rept. No. 36830; May 31, 1949; vol. II, FCC Rept. No. 54382; July 7, 1950.
[4] "Television Broadcast Service—Third Notice of Further Proposed Rule Making," FCC Rept. No. 47 CFR, pt. 3 (Docket Nos. 8736, 8975, 8976, 9175), March 21, 1951; "Sixth Report and Order," FCC Rept. No. 52-294, 74219 (Docket Nos. 8736, 3975, 9175, 8976), April 14, 1952.
[5] Since the interference ratios of Panel 6 apply at the receiver input, one needs only the antenna and lead line characteristics to transform the limit ratios to the antenna site. However, to use a different receiver as might be specified for another grade of service, the receiver characteristics would be required.
[6] "Engineering Aspects of Television Allocations," Rept. of the Television Allocations Study Organization to the Federal Communications Commission; March 16, 1959.
[7] Since receiver noise is actually generated in the receiver and not introduced at the antenna, its effect is slightly different. Here the FCC would have to specify the minimum field strength of desired signal at the receiver antenna site for each of the three grades of service.
[8] $F(50, 50)$ is a normalized field strength for 1-kw effective radiated power in the direction of the measurement point. $F'(L, T)$ is not normalized and is for a specified transmitter plant.
[9] Reference [6], pp. 403–412.
[10] "A Method of Predicting Average Field Strengths at Television Broadcast Frequencies," Appendix to Final Rept. of Committee 5.4 contained in the Final Rept. of TASO Panel 5.
[11] Howard T. Head, "The Influence of Trees on Television Field Strengths at Ultra High Frequencies," Appendix to Final Rept. of Committee 5.4 in Final Rept. of TASO Panel 5.
[12] A. H. LaGrone, "Forecasting Television Service Fields," Reference [6], pp. 413–447; and A. H. LaGrone, "Empirical Method for Determining the Effect of Uneven Terrain on the Television Signal at a Given Location," Appendix to Final Rept. of Committee 5.4, in Final Rept. of TASO Panel 5.
[13] In taking the quotient, there are other statistical requirements which, however, appear to be reasonably well satisfied in practice. The various $F_u'(50, 50)$ fields must not be correlated and the corresponding field distribution functions must be reasonably symmetrical about the mean.
[14] See also D. G. Fink, "Television Engineering Handbook," McGraw-Hill Book Co., Inc., New York, N. Y., pp. 14-26–14-32; 1957.
[15] D. C. Livingston, "Presentation of coverage information," this issue, p. 1102.
[16] "Report of Committee 5.3 Television Coverage Operator," Reference [6], Figs. 392–396. Also see Final Rept. of Panel 5—Analysis and Theory, Television Allocation Study Organization, the Final Rept. of Committee 5.3 including "Minority Report of TASO Committee 5.3," by Robert S. Kesby, attached thereto and the "Portrayal of Coverage" under "The Overall Technical Task of TASO."
[17] Reference [6], pp. 216–221, 356, 360 and 572–578.
[18] Reference [6], p. 287. See "Concluding Comments on Validity, Accuracy and Extensions," under "The Overall Technical Task of TASO," Final Rept. of Panel 5—Analysis and Theory, Television Allocation Study Organization.
[19] Reference [6], p. 393.
[20] Reference [6], p. 281.
[21] Reference [6], pp. 302–322.

CORRECTION

Britton Chance, author of "Electron Transfer in Biological Systems," which appeared on pages 1821–1840 of the November, 1959, issue of PROCEEDINGS, has requested another and more satisfactory reproduction of Fig. 31 (p. 1838), which appears below.

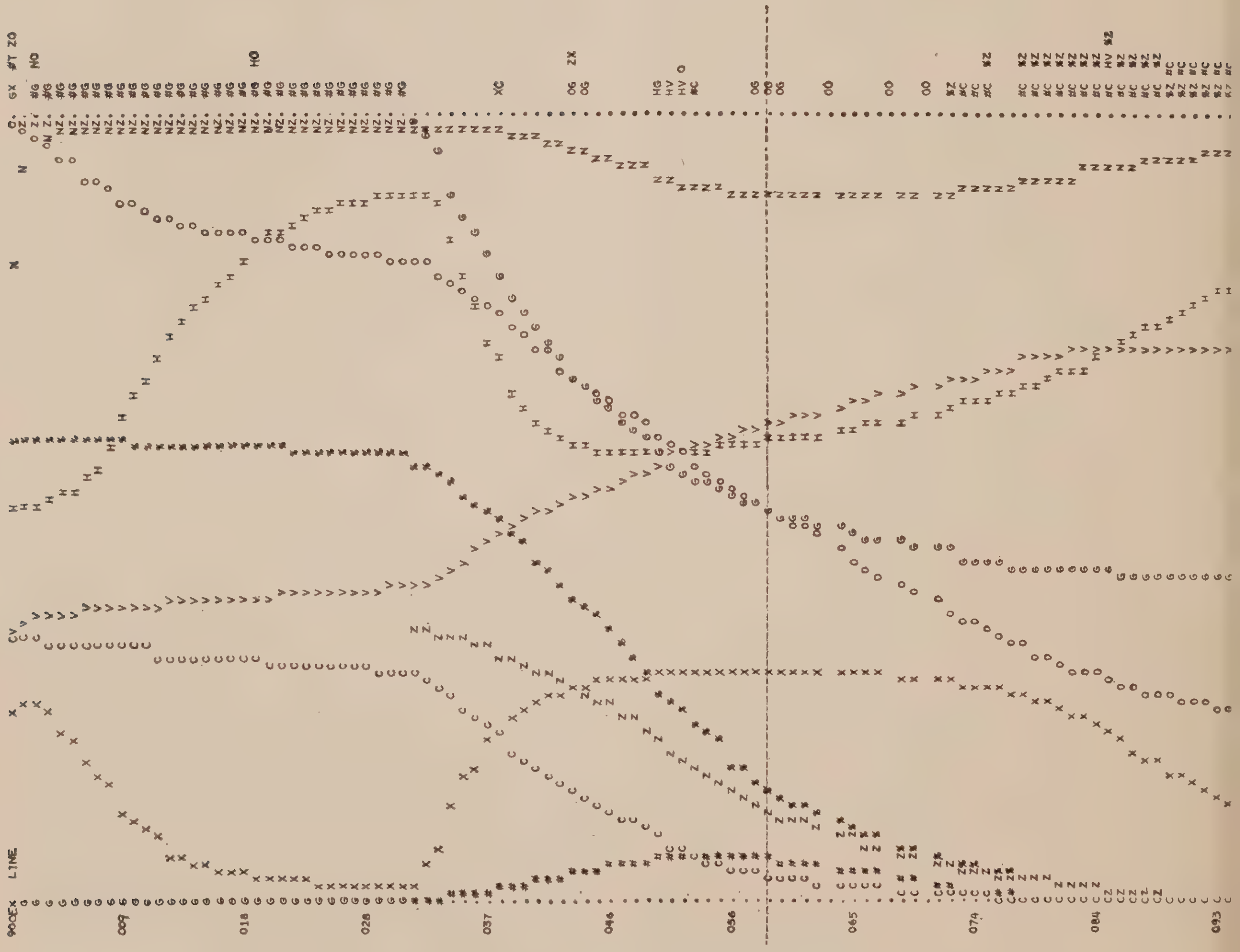
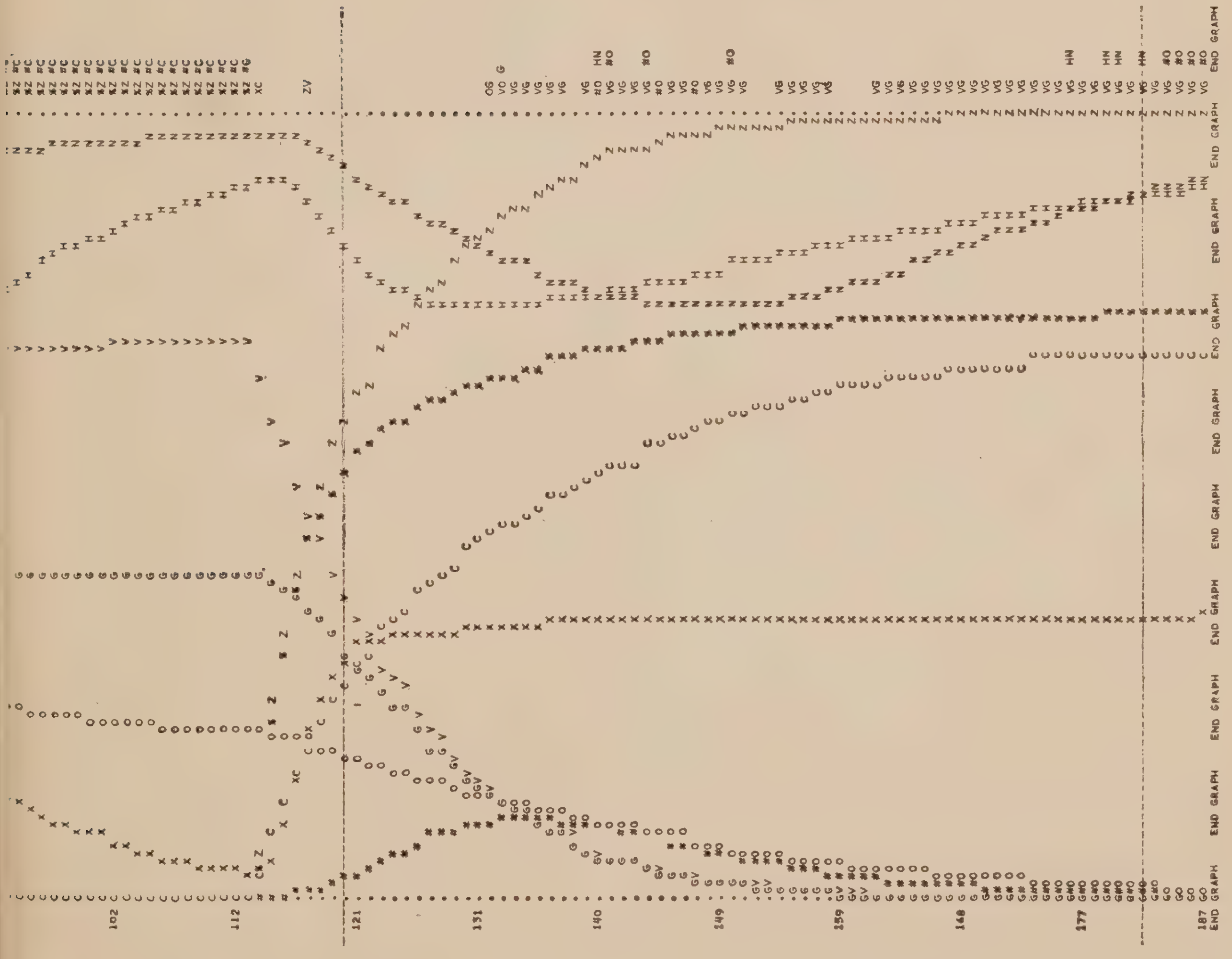


Fig. 31—High-speed printer record of the kinetics of ten intermediates in metabolic control systems of Figs. 29 and 30. The identification of the chemicals is given in Table II. The identification of the time scale at the bottom of the graph, the normalization of the concentrations for the variables and the key to the crossing over of the traces at the top of the graph, are explained in the text (DC-4). (Data obtained with Univac 1, with the aid of the University of Pennsylvania, Computer Center.)



IRE Standards on Television: Methods of Testing Monochrome Television Broadcast Receivers, 1960*

60 IRE 17. S1

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* Approved by the IRE Standards Committee, November 19, 1959. Reprints of this Standard 60 IRE 17. S1, may be purchased while available from the Institute of Radio Engineers, 1 East 79th Street, New York, N. Y., at $1.00 per copy. A 20 per cent discount will be allowed for 100 or more copies mailed to one address.

Part 1—INTRODUCTION

Chapter 1—General

1.1 *Object*

THIS standard replaces IRE Standard 48 IRE 22. S1, "Standards on Television: Methods of Testing Television Receivers, 1948."

At a later date, a standard for color television receivers will be introduced. Reference will be made in that standard to many portions of the present standard which are applicable to color television receivers as well as to monochrome receivers.

1.2 *Scope*

This standard describes procedures for measurement of the performance characteristics of the picture and sound sections of television receivers. Where specific test conditions are stated, these apply to home broadcast receivers designed to receive transmissions in accordance with the specifications of the United States Federal Communications Commission.[1] Where other conditions apply, appropriate modifications must be made.[2]

Emphasis is placed on over-all receiver performance. Internal characteristics such as the gains and bandwidths of individual stages are not generally considered.

1.3 *Standard Test Frequencies*

The range of standard test frequencies includes all of the allocated television channels. The present television channel allocations, where A includes frequencies from $470+6(C\text{-}14)$ to $470+6(C\text{-}13)$, and

$$P = 471.25 + 6(C\text{-}14)$$

$$S = 475.75 + 6(C\text{-}14),$$

are as follows:

Channel No.	Channel Allocation mc	Picture Carrier Frequency mc	Sound Carrier Frequency mc
2	54– 60	55.25	59.75
3	60– 66	61.25	65.75
4	66– 72	67.25	71.75
5	76– 82	77.25	81.75
6	82– 88	83.25	87.75
7	174–180	175.25	179.75
8	180–186	181.25	185.75
9	186–192	187.25	191.75
10	192–198	193.25	197.75
11	198–204	199.25	203.75
12	204–210	205.25	209.75
13	210–216	211.25	215.75
14	470–476	471.25	475.75
15	476–482	477.25	481.75
.	.	.	.
.	.	.	.
.	.	.	.
C	A	P	S
.	.	.	.
.	.	.	.
.	.	.	.
82	878–884	879.25	883.75
83	884–890	885.25	889.75

When measurements are not performed on all VHF channels, they should be made on Channels 4 and 10. The picture and sound carriers of these two channels are referred to as the *VHF standard test frequencies.*

Receivers which cover the entire UHF range should be measured on Channels 18, 48 and 79. The picture and sound carriers of these three channels are referred to as the *UHF standard test frequencies.*

1.4 *Standard Test Input Levels*

Input signal levels may be expressed in either of two ways:

a) In terms of available power (Section 1.4.1), in which case the input is preferably expressed in decibels below one watt.

b) In terms of input voltage, in which case the input is frequently expressed in microvolts or in decibels below one volt and the intended source resistance is stated.

When a standard composite picture signal is used, input level refers to the value during the synchronizing pulse interval. Where a picture carrier with sine-wave modulation is used, the input level is the value of the carrier in the absence of modulation.

Normally, two signal generators will be used so as to to supply both the sound and picture carriers. Unless otherwise specified, the outputs of these generators will be maintained equal.

1.4.1 Available Power. The available power is the power delivered by a generator to a matched load. It is equal to $E^2/(4R)$, where E is the rms open-circuit voltage of the generator and R is the internal resistance of the generator (including the dummy-antenna resistance). It is preferably expressed in decibels below 1 watt. The signal generator may be calibrated in terms of the available signal power and used on that basis, even though not matched exactly by the load impedance. If a signal generator is to be used with various values of dummy-antenna resistance, it should be calibrated in terms of the open-circuit voltage and the available power should be calculated from the above formula. When reference is made to values of power input, it is understood that the available power is meant.

1.4.2 Input Voltage. Input level in terms of voltage refers to the open-circuit voltage of a generator with an internal resistance, including the dummy-antenna resistance (Section 1.7), equal to the nominal input resistance of the receiver. By this definition, when the receiver input impedance is a resistance equal to the nominal input resistance, the input voltage (open-circuit voltage) is twice the voltage appearing across the antenna terminals of the receiver.

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[1] Rules and regulations of the Federal Communications Commission, pt. 3, Sec. 3.682.

[2] A related IEC Standard, "Recommended Methods of Measurement on Receivers for Television Broadcast Transmissions," is published by the International Electrotechnical Commission, 39, rue de Malagnou, Geneva, Switzerland.

Since the input impedance of television receivers built in the United States has been standardized at a value of 300 ohms, it has become common practice to express the input in microvolts, or in decibels below one volt. However, voltage measurements made on receivers designed for a different input impedance will not be directly comparable to those made on receivers designed for the standard 300-ohm impedance unless correction is made for the difference in input impedance.

1.4.3 Values of Standard Test Input Levels. Standard input levels are specified in Table I. Corresponding to these values of available power, which are independent of the receiver input impedance, are shown the approximate equivalent values of open-circuit voltage for the standard impedance level of 300 ohms.

TABLE I

Available Power, db below 1 watt	Approximate Equivalent Input Voltage for $R=300$ Ohms	
	microvolts	db below 1 volt
131	10	100
121	32	90
111	100	80
101	320	70
91	1000	60
81	3200	50
71	10,000	40
61	32,000	30
51	100,000	20

1.4.4 Standard Mean-Signal Input Power. The standard mean-signal input power is 81 db below 1 watt, corresponding to 3200 μv at 300 ohms.

1.5 Standard Picture Test Modulation

1.5.1 Sine Wave. The standard test modulation for sine-wave modulated signals shall be 30 per cent amplitude modulation at 400 cps.

1.5.2 White-Pattern Modulation. The standard test modulation envelope for white-pattern modulation shall be an RF signal modulated by the waveform standardized by the Federal Communications Commission and shown in Fig. 1.5.2 with the picture portion of the signal constant at 15 per cent of the carrier level during the synchronizing peaks.

1.5.3 Gray-Pattern Modulation. The standard test modulation envelope for gray-pattern modulation shall be an RF signal modulated by the synchronizing waveform of Fig. 1.5.2 with the picture portion of the signal constant at 40 per cent of the carrier level during the synchronizing peaks.

1.5.4 Test-Pattern Modulation. The standard for test-pattern modulation shall be an RF signal modulated by the EIA (Electronic Industries Association) test pattern (Fig. 1.5.4) with the white peaks at 15 per cent of the carrier level during the synchronizing peaks.

1.6 Standard Sound Test Modulation

Standard test modulation of the sound carrier is frequency modulation at 400 cps with a deviation of 7.5 kc; this is 30 per cent of the maximum system deviation of 25 kc.

The standard transmitter pre-emphasis provided by a time constant of 75 μsec is normally not employed in fidelity testing of the sound channel. Instead, the corresponding standard de-emphasis characteristic, shown in Fig. 1.6, is applied as a compensating correction to the amplitude-vs-frequency response. This procedure is described in Section 10.2.2.

1.7 Standard Dummy Antenna

The standard dummy antenna presents a balanced, resistive, 300-ohm source impedance to the antenna terminals of the television receiver. Signal generators that do not have these properties must be provided with an external network which may consist of resistors or of a balun.

The resistors used should have negligible reactive components, and in the case of two or more generators, the resistance networks should be located at the signal generators with a 300-ohm balanced line to the receiver. Most of the networks used with two or more signal generators require a correction factor for determining the open-circuit voltage from the generator voltage.

If a balun is used in place of a resistance network, its voltage transformation and impedance characteristics must be known with respect to frequency. If either of these characteristics is not reasonably flat, an iterative resistance attenuator network may be used to minimize departures from uniform transmission or termination.

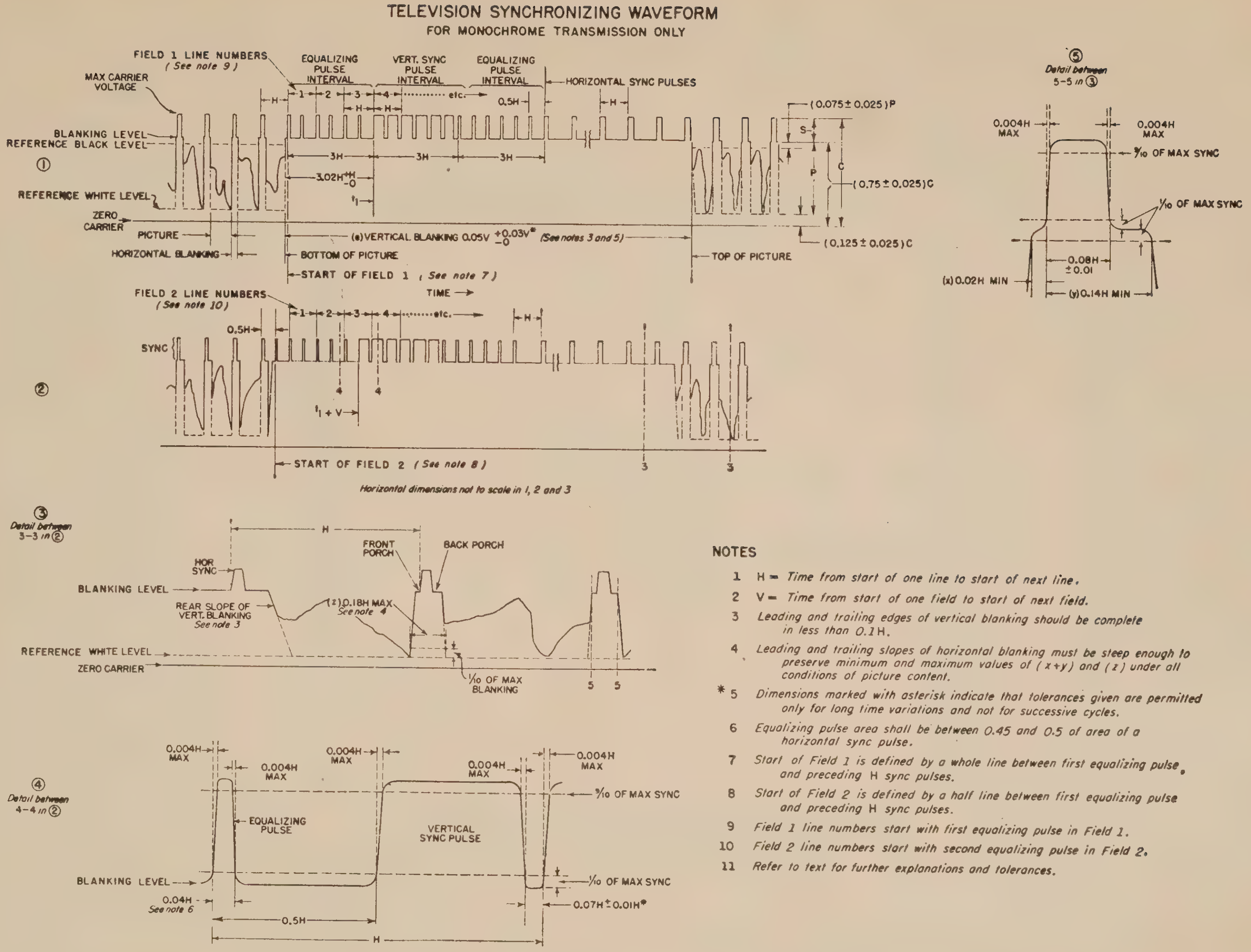
The effect of reversing the connections to the receiver antenna terminals and reversing the power-line connections of either the signal generator or the receiver or both should be noted. A change in the receiver output is an indication of unbalance in the dummy-antenna system; however, no change in receiver output does not necessarily indicate a balanced dummy-antenna system.

When more than one signal generator is used, a comparison should be made of the relative receiver output as each signal generator is tuned in turn to the same frequency, to obtain the appropriate correction.

The following paragraphs describe several examples of dummy-antenna configurations. In many instances, balun transformers can be used advantageously, particularly where it is desirable to effect impedance matching with a minimum power loss, or when the receiver has little unbalanced signal rejection.

1.7.1 Single Balanced Signal Generator. The network consists of two resistors of equal value, one connected in series with each terminal of the signal generator and of such value that the total output impedance, including the signal generator, is 300 ohms.

1.7.2 Single Unbalanced Signal Generator. The network consists of two resistors, a 150-ohm resistor connected in series with the "ground" terminal of the signal generator and a resistor (equal to 150 ohms minus


TELEVISION SYNCHRONIZING WAVEFORM
FOR MONOCHROME TRANSMISSION ONLY
FIELD 1 LINE NUMBERS (See note 9)
MAX CARRIER VOLTAGE
EQUALIZING PULSE INTERVAL
VERT. SYNC PULSE INTERVAL
EQUALIZING PULSE INTERVAL
HORIZONTAL SYNC PULSES
BLANKING LEVEL
REFERENCE BLACK LEVEL
①
REFERENCE WHITE LEVEL
ZERO CARRIER
PICTURE
HORIZONTAL BLANKING
H
1 2 3 4 etc.
0.5H
3H
3.02H +H -0
t1
(0.075 ± 0.025) P
S
P
C
(0.75 ± 0.025) C
(0.125 ± 0.025) C
(e) VERTICAL BLANKING 0.05V +0.03V* -0 (See notes 3 and 5)
BOTTOM OF PICTURE
START OF FIELD 1 (See note 7)
TOP OF PICTURE
TIME →
FIELD 2 LINE NUMBERS (See note 10)
SYNC
②
t1 + V
START OF FIELD 2 (See note 8)
3
Horizontal dimensions not to scale in 1, 2 and 3
③ Detail between 3–3 in ②
HOR SYNC
FRONT PORCH
BACK PORCH
REAR SLOPE OF VERT. BLANKING See note 3
(z) 0.18H MAX See note 4
REFERENCE WHITE LEVEL
ZERO CARRIER
1/10 OF MAX BLANKING
5
④ Detail between 4–4 in ②
0.004H MAX
EQUALIZING PULSE
VERTICAL SYNC PULSE
9/10 OF MAX SYNC
1/10 OF MAX SYNC
0.04H - See note 6
0.07H ± 0.01H*
0.5H
⑤ Detail between 5–5 in ③
0.08H ± 0.01
(x) 0.02H MIN
(y) 0.14H MIN

NOTES

1 H = Time from start of one line to start of next line.
2 V = Time from start of one field to start of next field.
3 Leading and trailing edges of vertical blanking should be complete in less than 0.1 H.
4 Leading and trailing slopes of horizontal blanking must be steep enough to preserve minimum and maximum values of (x+y) and (z) under all conditions of picture content.
*5 Dimensions marked with asterisk indicate that tolerances given are permitted only for long time variations and not for successive cycles.
6 Equalizing pulse area shall be between 0.45 and 0.5 of area of a horizontal sync pulse.
7 Start of Field 1 is defined by a whole line between first equalizing pulse and preceding H sync pulses.
8 Start of Field 2 is defined by a half line between first equalizing pulse and preceding H sync pulses.
9 Field 1 line numbers start with first equalizing pulse in Field 1.
10 Field 2 line numbers start with second equalizing pulse in Field 2.
11 Refer to text for further explanations and tolerances.

Fig. 1.5.2—Television synchronizing waveform for monochrome transmission.

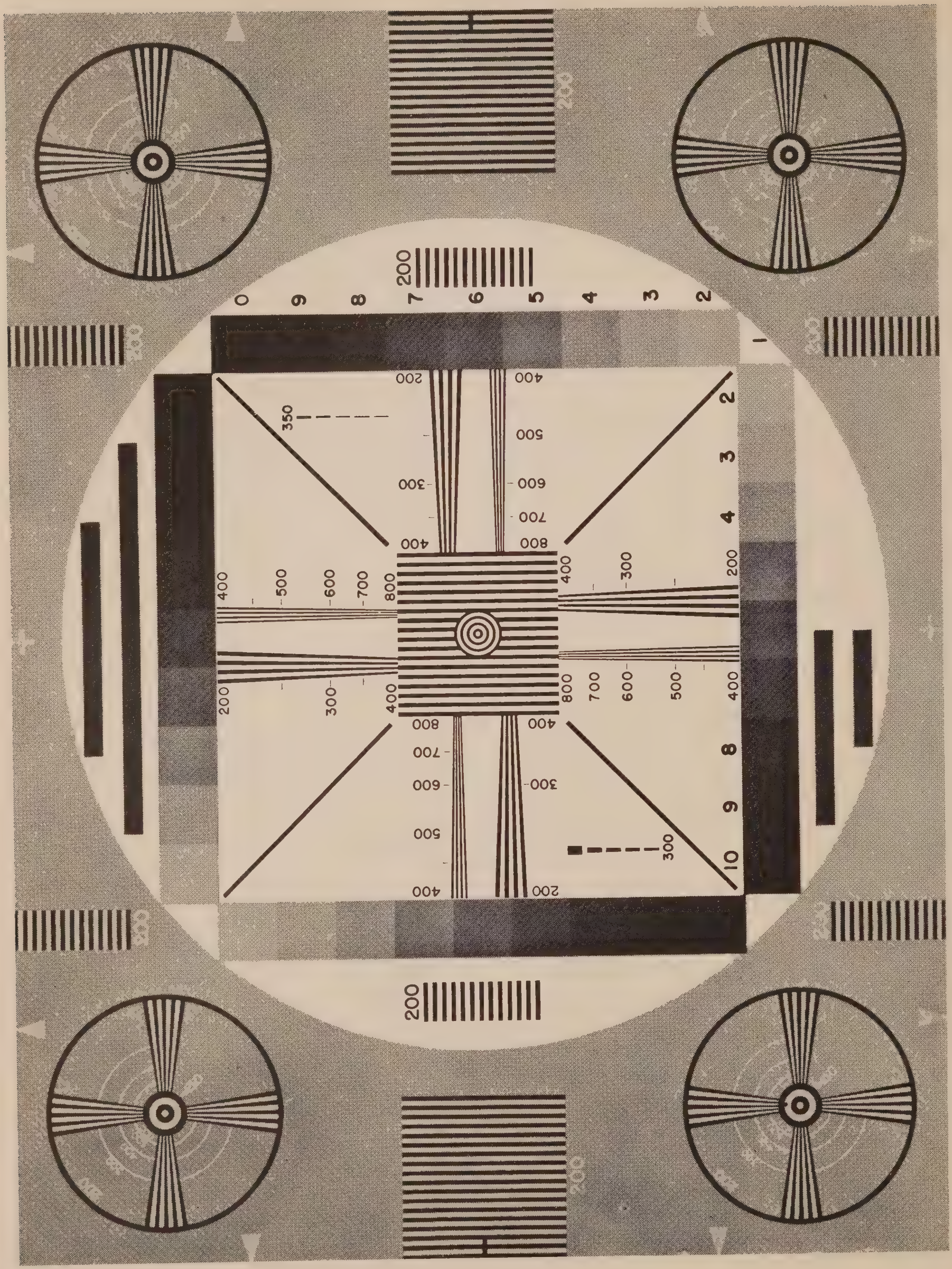

200
0
9
8
7
6
5
4
3
2
1
200
350
300
400
500
600
700
800
2
3
4
10
9
8
300
200

Fig. 1.5.4—EIA resolution chart.

the generator output impedance) in series with the output terminal of the signal generator.

1.7.3 Two Signal Generators. Separate picture and sound signal generators may be connected as shown in Fig. 1.7.3. The open-circuit voltages obtained from the connections of Fig. 1.7.3(a) and 1.7.3(c) are one-half the generator open-circuit voltages.

Fig. 1.7.3(c) illustrates a special case in which signal generators with 300-ohm output impedance are employed. The dummy-antenna network provides an impedance match to the signal generator outputs as well as the required source impedance to the receiver

1.7.4 Three Signal Generators. For certain measurements, a third signal generator may be required. The two connections shown in Fig. 1.7.4 provide an open-circuit voltage that is one-third the generator open-circuit voltage.

Fig. 1.7.4(b) illustrates a special case in which signal generators with 300-ohm output impedance are employed and the dummy-antenna network provides an impedance match to the generator output.

1.8 Standard Picture Test Output

The standard picture test output as delivered by the receiver to the controlled element of the picture tube shall have an amplitude of 20 volts between blanking level and white, as determined by a cathode-ray oscilloscope when using the standard white-pattern modu-

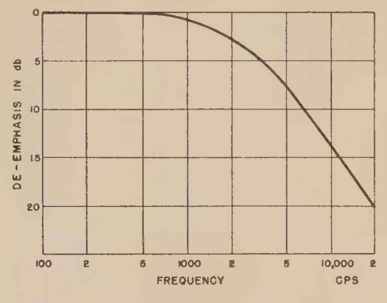
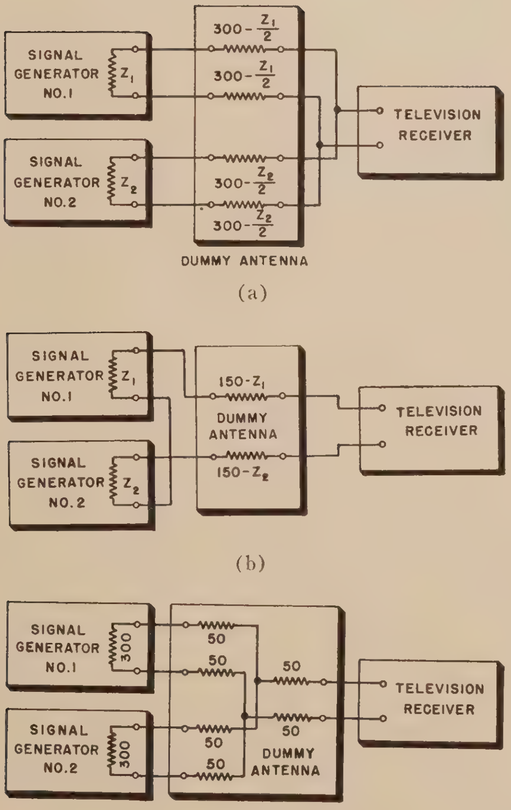


Fig. 1.6—Standard de-emphasis curve.

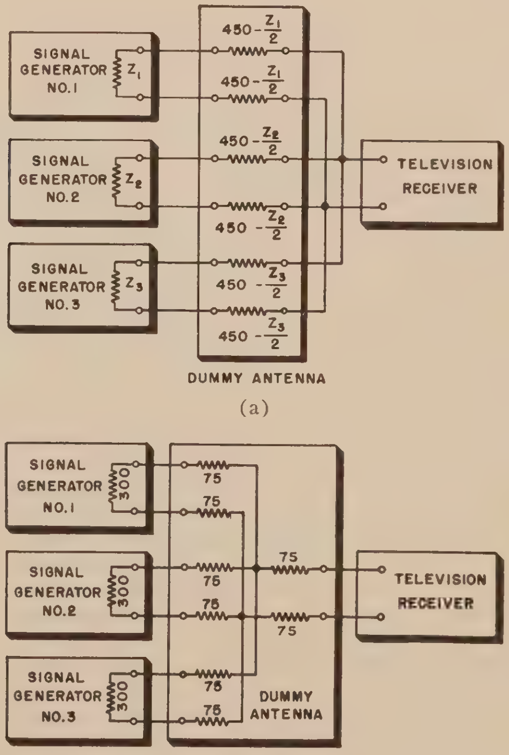

SIGNAL GENERATOR NO.1
Z_1
SIGNAL GENERATOR NO.2
Z_2
$300-\frac{Z_1}{2}$
$300-\frac{Z_1}{2}$
$300-\frac{Z_2}{2}$
$300-\frac{Z_2}{2}$
DUMMY ANTENNA
TELEVISION RECEIVER
$150-Z_1$
$150-Z_2$
DUMMY ANTENNA
300
300
50
50
50
50
50
50
DUMMY ANTENNA

(a)

(b)

(c)

Fig. 1.7.3—Dummy-antenna connections for two signal generators. (a) Two signal generators in parallel. (b) Two signal generators in series. (c) Two 300-ohm signal generators in parallel.


SIGNAL GENERATOR NO.1
Z_1
SIGNAL GENERATOR NO.2
Z_2
SIGNAL GENERATOR NO.3
Z_3
$450-\frac{Z_1}{2}$
$450-\frac{Z_1}{2}$
$450-\frac{Z_2}{2}$
$450-\frac{Z_2}{2}$
$450-\frac{Z_3}{2}$
$450-\frac{Z_3}{2}$
DUMMY ANTENNA
TELEVISION RECEIVER
300
300
300
75
75
75
75
75
75
75
75
DUMMY ANTENNA

(a)

(b)

Fig. 1.7.4—Dummy-antenna connections for three signal generators. (a) Three signal generators in parallel. (b) Three 300-ohm signal generators in parallel.

lation (Section 1.5.2). When using symmetrical sine-wave modulation (Section 1.5.1), the standard output shall be 20 volts peak-to-peak. These outputs are equivalent for a receiver having a linear relationship between input and output over the amplitudes involved, as shown in Fig. 1.8. If the particular receiver being measured has been designed to operate with a picture device whose operating voltage requirements are so different from the conventional picture tube as to make the above value of 20 volts unsuitable, a value should be chosen to be approximately one-half of the normal maximum input voltage for the particular picture device being used. The value so chosen should be included in the data.

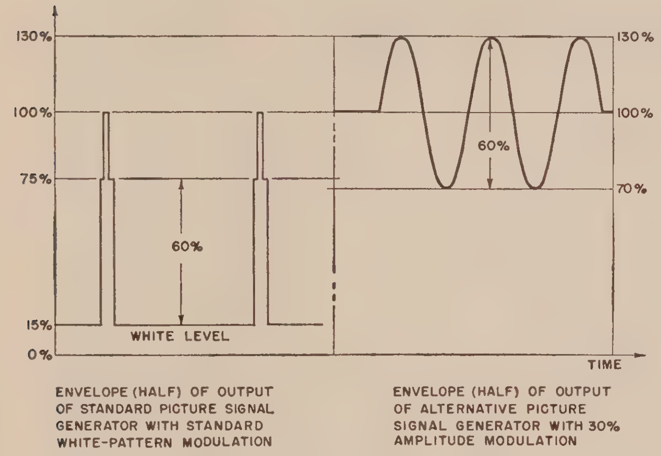


Fig. 1.8—Equivalence of output from standard white-pattern modulation and alternate 30 per cent amplitude modulation.

1.9 Standard Sound Test Output

1.9.1 Standard Test Output. For receivers capable of delivering at least 1 watt at 10 per cent distortion (Section 10.3), the standard test output is an audio-frequency power of 0.5 watt delivered to a standard dummy load. For receivers capable of delivering 0.1 watt but less than 1 watt at 10 per cent distortion, the standard test output is 0.05 watt of audio-frequency power delivered to a standard dummy load. When this latter value is used, it should be specified.

1.9.2 Standard Dummy Load. Output measurements of the sound section of a television receiver are made in terms of the power delivered to a standard dummy load substituted for the loudspeaker, except in special cases where other terminations are specified. The standard dummy load is a pure resistance whose value is equal to the absolute value of the 400-cps impedance of the loudspeaker. Where an output transformer is connected between the receiver and the loudspeaker, the output transformer is treated as part of the receiver.

1.10 Standard Test Conditions

1.10.1 General. It is assumed that the following standard test conditions are in effect during all tests unless noted otherwise.

1.10.2 Power Supply. Receiver measurements are made at the supply voltage for which the receiver is designed. Mean values of voltage and frequency are arbitrarily selected, such as 117 volts and 60 cps for ac operated receivers. Certain receiver characteristics may be desired at other than standard supply voltages and frequencies, or over a range of operating values. Tests should be made to check whether the receiver operates satisfactorily over the range of operating voltage and frequency likely to be encountered in service.

1.10.3 Ambient Temperature and Humidity. The ambient temperature should be between 20° and 35° C, and the relative humidity should be below 90 per cent.

1.10.4 Electron Devices. The electron tubes or other devices used should have standard rated values of those characteristics which significantly affect the performance of the receiver.

1.10.5 Television Receiver Adjustments.

1.10.5.1 General. All control settings not otherwise specified should be adjusted for normal reception. The synchronizing controls are adjusted for proper synchronization and best interlace. The contrast control is adjusted for maximum focused luminance (Section 3.9), unless otherwise stated, and the brightness control is set so that the line structure just disappears in the darkest portion of the gray scale. The scanning linearity, the scanning amplitude, and the focus adjustments are optimized.

1.10.5.2 Tuning adjustments. The receiver is normally tuned so that the local oscillator operates at the correct frequency, corresponding to the selected channel. This adjustment can be made by measuring either the local oscillator frequency or the picture carrier intermediate frequency (nominally 45.75 mc) with a frequency meter.

When measuring peak picture and peak sound sensitivity, the receiver is tuned as described for these tests (Sections 4.3 and 8.4).

Chapter 2—Requirements and Characteristics of Test Apparatus

2.1 Standard Picture Signal Generator

The standard picture signal generator should provide a signal with the following characteristics:

a) The generator should be capable of modulation by the waveform of Fig. 1.5.2 to produce a modulated signal whose characteristics are in accordance with the Rules and Regulations of the Federal Communications Commission.[1]

b) The amplitude-vs-frequency characteristic should display less than 0.5-db response difference for any two modulating frequencies in the range from 30 cps to 4.5 mc. The time-delay errors should be negligible within this frequency band. Ideally a vestigial-sideband filter is required; however, most receiver tests can be made without this filter (Section 6.2.2).

c) The output voltage should be adjustable to any value over the range between 1 and at least 200,000 μv. Higher outputs up to 2 volts are desirable. The output-level indicator should measure the output during synchronizing peaks.

d) Incidental phase modulation of the carrier should not exceed 10 degrees swing at full video modulation at any carrier frequency.

e) Extraneous frequency modulation (hum) of the carrier should be negligible with respect to the characteristic under observation, especially when the generator is to be used in connection with the sound signal generator (Section 2.3) for tests on the sound channel.

2.2 Alternative Picture Signal Generator

Although the complete performance testing of the picture section cannot be accomplished without the use of a standard picture signal generator and a pattern generator, as described in Sections 2.1 and 2.4, many tests can be made with a standard signal generator producing a sine-wave 30 per cent amplitude-modulated signal. Furthermore, certain of the standard tests can be facilitated by the use of this type of signal generator. This generator should have a frequency range extending from below the intermediate frequency up to the highest television channel plus twice the intermediate frequency of the receiver under test, should be capable of amplitude modulation at 400 cps, and should have a variable output voltage up to at least 200,000 μv and preferably 2 volts.

Extraneous frequency modulation of the carrier should be negligible with respect to the characteristic under observation, especially when the generator is to be used in connection with the sound signal generator (Section 2.3) for tests on the sound channel. The carrier frequency stability should be consistent with the requirement of Section 2.3(d).

2.3 Sound Signal Generator

The sound signal generator should have the following characteristics:

a) The output should be calibrated from 1 to 200,000 μv with a constant source impedance.

b) It should be capable of frequency modulation at rates of 30 to 15,000 cps to a deviation of at least 25 kc and preferably to 50 kc with negligible distortion, and negligible incidental amplitude modulation.

c) Amplitude and frequency modulation at power-line frequencies should be negligibly small.

d) The carrier frequency should be sufficiently stable to maintain an accuracy of ±5 kc in the 4.5-mc difference frequency between the sound and picture carriers.

2.4 Pattern Generator

This equipment, which supplies a modulating signal to the picture signal generator, must contain means for generating a composite signal which will contain not only those picture elements which comprise a test pattern, but also correctly timed blanking and synchronizing pulses. The characteristics of the standard synchronizing waveforms are given in Fig. 1.5.2.

The pattern generator must be provided with the necessary controls and monitoring means to assure the correct levels of the various components of the composite picture signal. It must be free of hum, noise, and other extraneous components.

In addition to the standard synchronizing-signal waveforms, the pattern generator should be capable of providing the following composite picture test patterns:

a) The white-pattern modulation of Section 1.5.2.

b) Gray-pattern modulation of Section 1.5.3.

c) Sine-wave modulation for frequencies of 100 kc to 4.5 mc.

d) Square-wave modulation of variable repetition rate capable of being synchronized with the sweep frequencies.

e) Staircase patterns arranged to appear as vertical stripes and to be movable over the entire picture.

f) The monoscope type of test pattern (Fig. 1.5.4).

g) A cross-hatch pattern in which the video component consists of two sets of synchronized narrow rectangular pulses at time intervals equal respectively to not more than $\frac{1}{16}$ of the vertical and horizontal scanning intervals. These pulses produce a cross-hatch pattern of stationary vertical and horizontal lines.

2.5 Wide-Band Cathode-Ray Oscilloscope

A calibrated wide-band oscilloscope is required for testing the performance of the picture circuits of a television receiver. Its phase and amplitude response must be such as to avoid significant distortion of any waveform of interest; the major requirements are that the deflection sensitivity difference between any two frequencies from 30 cps to 4.5 mc should be less than 0.5 db and that the time-delay error be negligible.

The input impedance should be high enough so that the performance of the circuits to which the oscilloscope is connected is not affected by the resistance or capacitance of the oscilloscope input circuits.

2.6 Audio-Output and Distortion-Measuring Devices

Apparatus for the measurement of audio output and distortion is the same as that required for the testing of frequency-modulation receivers.[3] The output meter should measure true rms values.

2.7 Measurement of Luminance

The photometer used in all luminance measurements should be capable of operating over a small area of the image. An instrument having an acceptance angle of 1 degree operated at a distance from the image equal to four times the picture height is suitable. The instrument should preferably be of the objective type and should simulate the color response of the average human eye. If the instrument is of the subjective matching type, a calibrated filter should be fitted to secure optimum color match.

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[3] See Section 3 of IRE Standards, 47 IRE 17. S1, "Standards of Radio Receivers: Methods of Testing Frequency-Modulation Broadcast Receivers, 1947."

Since ambient lighting is variable, the effect of this should be assessed separately. Ambient lighting includes reflections of the television picture from surrounding objects, and a check should be made with the receiver operating at maximum brightness to verify that the luminance of the light reflected from any object does not exceed 0.2 foot-lambert.

When subjective methods are used, sufficient time should elapse before measurements are taken in order to condition the eye to the low level of ambient illumination. Unless otherwise stated, all luminance measurements should be taken at the center of the relevant area in a direction parallel to the optical axis of the picture screen.

2.8 Shielded Enclosure

A shielded enclosure is required for some television receiver measurements in order to attenuate external signals that might otherwise affect the measurements.

Part II—PICTURE SECTION OF RECEIVER

Chapter 3—Picture Quality

3.1 General Considerations

Picture quality depends on characteristics which include size, resolution, contrast range, transfer characteristic, geometric distortion, interlace, luminance, and focus. These may be measured or evaluated by viewing the image of suitably designed test charts. One test chart recommended for this purpose is shown in Fig. 1.5.4 and is described in Standard RS-170 of the Electronic Industries Association. Other useful charts are described under the applicable sections of this standard.

The pattern generator (Section 2.4) makes use of a camera or scanner focused on the chart, or a monoscope containing a copy of the chart. The modulation level of the picture signal generator is set with the whitest portion of the gray scale of the chart at reference white level (15 per cent) and the darkest portion of the gray scale at reference black level (Fig. 1.5.2).

The receiver is tuned in accordance with Section 1.10.5.2 with standard mean-signal input, and the controls are adjusted as in Section 1.10.5.1.

3.2 Picture Size

3.2.1 Definition. The picture size is described by four projected quantities: Picture diagonal, maximum picture height, maximum picture width and picture area. Linear dimensions are specified in inches and area in square inches.

3.2.2 Method of Measurement. The projected dimensions are determined by means of a sliding gauge or other suitable device. Another method consists of photographing the picture area from a point situated on the optical axis of the area at a distance equal to at least five times the maximum picture height. From this photograph, the projected dimensions, as well as the picture area, are determined.

3.3 Curvature of Picture Screen

3.3.1 Definition. The curvature of the picture screen is defined by the ratio between the picture depth and the maximum picture height. The picture depth is defined as the distance between two geometrical planes, both perpendicular to the optical axis, one going through the image point nearest to the observer and the other going through the most distant image points of the picture area.

3.3.2 Method of Measurement. The picture depth is measured with the aid of a traveling microscope or other suitable means.

3.4 Geometric Distortion

In the television transmitter, the coordinates of the picture elements are translated into time differences in the television signal. In the receiver the reverse process must take place in order to obtain undistorted reproduction. Any deviation from the desired linear relationship between timing and position due to the receiver is defined as geometric distortion.

Geometric distortion is measured by using an electrical time pattern generator [Section 2.4(g)] in which the video information consists of two sets of synchronized pulses, at equidistant time intervals, representing a cross-hatch pattern of horizontal and vertical lines. Detailed procedures for measuring geometric distortion are given in IRE Standards, 54 IRE 23. S1.[4]

3.5 Nonlinearity

3.5.1 Definition. Scanning nonlinearity is defined in terms of the pattern of horizontal and vertical lines produced by the cross-hatch pattern generator [Section 2.4(g)]. The horizontal nonlinearity is the departure of the spacing between any two adjacent vertical lines from the mean spacing between the lines expressed as a percentage of the mean spacing between the lines. Vertical nonlinearity is defined similarly. Both horizontal and vertical nonlinearities are measured along projected horizontal and vertical lines through the center of the picture area.

3.5.2 Method of Measurement. A cross-hatch pattern generator is used [Section 2.4(g)]. To determine the nonlinearity, a photograph of the reproduced pattern may be taken as in Section 3.2. Alternatively, a traveling microscope or other suitable means may be used to measure the distance between adjacent intersection points of the projected pattern.

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[4] "IRE Standards on Television: Methods of Measurement of Aspect Ratio and Geometric Distortion," PROC. IRE, vol. 42, pp. 1098–1103; July, 1954.

3.5.3 Presentation of Data. The nonlinearity is plotted on a linear time scale as abscissa and a linear percentage scale as ordinate. The equal time intervals corresponding to the divisions of the picture area as transmitted are marked on the abscissa.

The difference between the mean distance and the distance between adjacent points is plotted as a percentage of the mean distance, at the center of each time interval. Graphs are plotted for both vertical and horizontal nonlinearity.

Short-time nonlinearity of scanning, such as results from yoke ringing, may not appear. To measure such deviations a more closely spaced pattern is necessary.

3.6 Raster Distortion

3.6.1 Definition. Raster distortion is the deviation from a true rectangle of the largest completely visible contour of approximately the correct aspect ratio formed by the test pattern.

3.6.2 Method of Measurement. An electrically generated cross-hatch test pattern [Section 2.4(g)] is used.

A photograph of the reproduced pattern may be taken under the same conditions as specified in Section 3.2.

On this photograph, or a similar projection of the reproduced pattern on a plane perpendicular to the optical axis, the distorted reproduction of the contour of the largest completely visible rectangle formed by the test pattern and having approximately the correct aspect ratio is traced (Fig. 3.6.2). This contour is normally an adequate description of raster distortion.

If one form of distortion predominates, it may be measured in accordance with the following methods. Fig. 3.6.2 represents a generalized contour. The corner points A, B, C and D are marked, and the auxiliary lines AB, BC, CD, DA, KF and HE are then drawn so that $AE=EB$, $BF=FC$, $CH=HD$, $DK=KA$.

The greatest distance between the line AB and the contour section between A and B lying outside the quadrangle $ABCD$ is called a_2.

The distance between AB and the point of the contour section lying farthest away from AB inside the quadrangle $ABCD$ is called a_1. The distances b_1, b_2, c_1, c_2, d_1 and d_2 are similarly defined.

The following distortion percentages are specified:

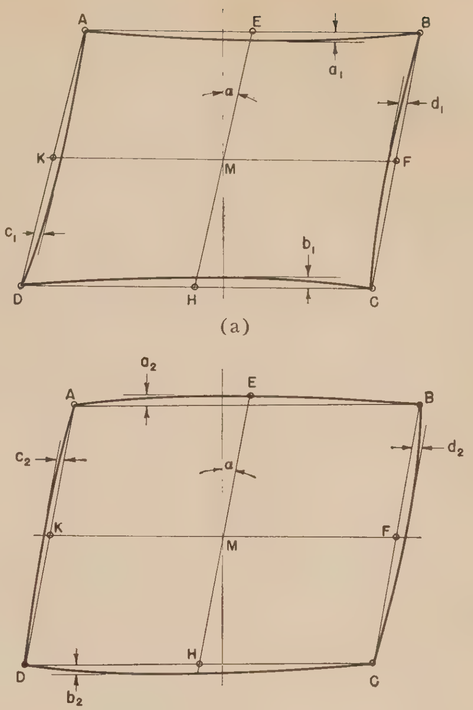
Horizontal Trapezoid Distortion

$$T_H = \frac{AD - BC}{AD + BC} \cdot 100 \text{ per cent}$$

and

Vertical Trapezoid Distortion

$$T_V = \frac{AB - DC}{AB + DC} \cdot 100 \text{ per cent.}$$



(a)

(b)

Fig. 3.6.2—Raster distortion measurements. (a) Pincushion distortion. (b) Barrel distortion.

If the contour sections AB as well as DC lie completely *outside* the quadrangle $ABCD$, the

Horizontal Barrel Distortion

$$B_H = 2\frac{a_2 - b_2}{AD + BC} \cdot 100 \text{ per cent.}$$

If the contour sections AB as well as DC lie completely *within* the quadrangle $ABCD$, the

Horizontal Pinchushion Distortion

$$C_H = 2\frac{a_1 + b_1}{AD + BC} \cdot 100 \text{ per cent.}$$

Similarly, the

Vertical Barrel Distortion

$$B_V = 2\frac{c_2 + d_2}{AB + CD} \cdot 100 \text{ per cent}$$

and the

Vertical Pincushion Distortion

$$B_V = 2\frac{c_1 + d_1}{AB + CD} \cdot 100 \text{ per cent.}$$

Parallelogram Distortion is expressed by the angle in degrees.

Ripple Distortion of the contour is present when the raster contour sections AB, CD, BC, DA show undulations. The peak-to-peak value of such undulations may be expressed as a percentage of raster height or width.

3.7 *Influence of Hum on Geometric Distortion and Brightness*

Geometric distortion and brightness irregularities may occur as a result of power-supply voltages and power-supply magnetic and electric fields. These effects can be distinguished by operating the receiver from a supply having a frequency differing slightly (*e.g.*, 1 cps) from the field frequency. Alternatively, if the receiver uses a power supply to which the picture synchronizing-signal generator is locked, the necessary relative phase changes may be obtained by rotating a suitable manual phase shifter in the lock-in circuit of the synchronizing-signal generator through 360 degrees.

With respect to geometric distortion, the excursion of the points in the picture which have the greatest vertical and horizontal movements are noted. The picture center should be offset (and the background brightness increased) so that the raster edges can be observed. This enables a determination of the degree of raster motion and synchronizing timing variation.

Brightness variations normally appear as moving horizontal bands. The receiver contrast and brightness controls may be adjusted to produce a gray background to facilitate observation of the shading.

The faults observed in this section are described together with the conditions of measurement.

3.8 *Luminance*

For a specified set of conditions, the maximum luminance of a television picture may be limited by factors which include deterioration of focus, geometric or size distortion, inadequate video drive, and the relative area of the picture at the peak white level. Flicker, which is generally not a limiting factor, is not considered here. See Section 2.7 for method of measurement.

3.9 *Maximum Focused Luminance*

3.9.1 Definition. This is the maximum luminance at which the focus is sufficient to resolve the line structure.

3.9.2 Method of Measurement. Apply to the receiver the standard test-chart modulated signal (Fig. 1.5.4) at mean-signal input level. Increase the luminance level to obtain the maximum luminance at which the focus is still sufficiently good to show line structure in maximum luminance areas near the center of the raster, with the focus control optimized.

3.9.3 Presentation of Data. The luminance is expressed in foot-lamberts, together with a description of the uniformity of focus over the raster.

3.10 *Maximum Usable Luminance*

The maximum usable luminance is measured with the same setup used to measure maximum focused luminance (Section 3.9.2). The luminance level is increased until significant degradation of the picture occurs for reasons other than defocusing. This luminance value is recorded as the maximum usable luminance together with a statement of the limiting condition.

3.11 *Contrast*

3.11.1 Introduction. Contrast is the ratio of the luminance of a peak white area of the picture screen to the luminance of a black area of the picture screen. Contrast may be limited by halation effects in the display device, by ambient illumination, or by severe nonlinearity in the luminance transfer characteristic. The first two are considered in this section and the third in Section 3.14.

3.11.2 Halation-Limited Contrast. The degree to which contrast is limited by halation effects is influenced by the following factors:

a) The relative size of black and white areas. In general, contrast decreases as a greater portion of the screen is excited by electrons. See Fig. 3.11.2(a).

b) The relative distance between points at which contrasting luminances are measured. In general, the contrast decreases as the distance between the measurement points decreases. See Fig. 3.11.2(b).

c) The presence of high luminance areas at the corners or edges of the picture. Scattering of electrons from the neck or sides of the picture tube may limit contrast. See Fig. 3.11.2(c).

3.11.2.1 Method of measurement of halation-limited contrast. Halation-limited and electron-scattering contrast are measured using the test charts shown in Fig. 3.11.2. The picture-tube beam current must be cut off in the black (shaded) areas of the picture. The white areas of the picture are at maximum focused luminance. The ambient illumination should be negligible.

a) Halation-limited large area contrast (α_l) is measured with the test chart shown in Fig. 3.11.2(a):

$$\alpha_l = \frac{2L_2}{L_1 + L_3}\,.$$

b) Halation-limited detail contrast (α_d) is measured with the test chart of Fig. 3.11.2(b):

$$\alpha_d = \frac{L_2 + L_3 + L_4 + L_5}{4L_1}\,.$$

c) Electron-scattering-limited large area contrast (α_s) is measured with the test chart of Fig. 3.11.2(c):

$$\alpha_s = \frac{L_2 + L_3 + L_4 + L_5}{4L_1}\,.$$

3.11.3 Contrast Limited by Ambient Illumination. With ambient illumination the luminance values of the black and white areas of the picture are increased by an equal amount, thus reducing the contrast. If, without ambient illumination, the luminance of a black area is L_b and the luminance of a white area is L_w, the large area contrast is

$$\alpha_l = \frac{L_w}{L_b}\,.$$

With ambient illumination, an amount L_r is added to

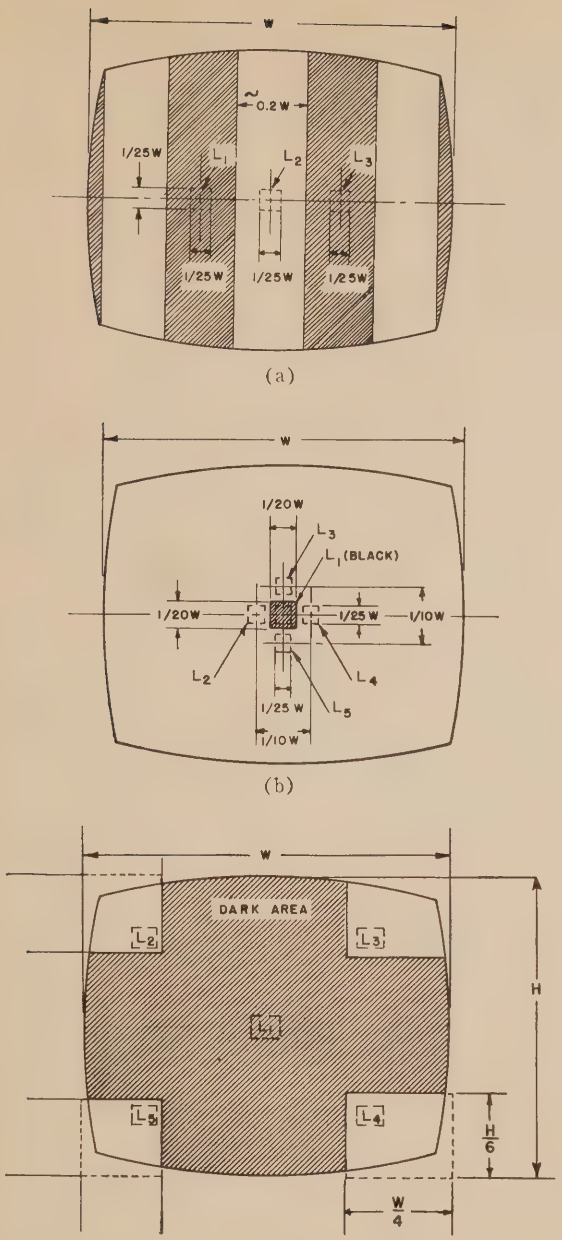


Fig. 3.11.2—(a) Test pattern for measurement of halation-limited large-area contrast. (b) Test pattern for measurement of halation-limited detail contrast. (c) Test chart for measurement of electron-scattering-limited large-area contrast.

L_b and L_w. L_r is the luminance due to the ambient light reflected by the picture screen. If ρ is the reflection coefficient of the picture screen (Section 3.11.4) and L_0 is the luminance caused by the ambient illumination with $\rho=1$, then

$$L_r = \rho L_0.$$

Thus the contrast with ambient illumination (α_i) becomes

$$\alpha_i = \frac{L_w + L_r}{L_b + L_r} = \frac{L_w + \rho L_0}{L_b + \rho L_0}.$$

3.11.4 Reflection Characteristic of the Picture Screen.

3.11.4.1 Definitions. The reflection characteristic of the picture screen is the luminance value in the direction of the optical axis as a function of the angle of incidence of the ambient illumination relative to the luminance value of an ideally diffuse surface with the same ambient illumination, the receiver being switched off.

3.11.4.2 Method of measurement. The front of the receiver is illuminated by a source of light equivalent to Standard Illuminant *C*. A magnesium carbonate block is placed on the optical axis in contact with and in front of the optical surface nearest to the viewer.

The luminance values of the magnesium carbonate block and the face of the receiver adjacent to the carbonate block are measured. The measurement is repeated as the angle of incidence of the light is varied.

3.11.4.3 Presentation of data. The results are expressed as the ratio between the luminance of the face of the receiver and that of the magnesium carbonate block corrected for its known reflectance. This ratio is plotted as a function of the angle of incidence.

3.12 Resolution and Focus

3.12.1 Definition. The vertical and the horizontal resolution is expressed as the maximum number of lines which can be resolved in the vertical and the horizontal directions as read from the resolution wedges on a reproduction of the standard test chart, Fig. 1.5.4.

3.12.2 Method of Measurement. The receiver is set up as in Section 3.1 with standard test-chart modulation. The focus should be adjusted in such a manner that the best over-all compromise is obtained. The nominal resolution is read at the point along the converging lines beyond which each individual line cannot be recognized with certainty. The resolution is recorded in the center and in the four corners of the picture. The highlight luminance should be specified.

3.13 Electrical Fidelity

The electrical fidelity is measured in Chapter 6, which describes measurement of the high-frequency step response (Section 6.4) and the line and field-rate step responses (Section 6.5). These data should be supplemented by a description of the test-chart reproduction, with the receiver adjusted as in Section 3.1. Ringing, overshoot, smear, and line or field shading should be described qualitatively.

3.14 Luminance Transfer Characteristic

3.14.1 Definition. The luminance transfer characteristic represents the relationship between the luminance and the corresponding picture modulation percentage.

3.14.2 Method of Measurement. A television signal at standard mean-signal level, modulated with the staircase pattern of Section 2.4(e) consisting of vertical bars equally distributed through the gray scale, is applied to the receiver terminals. The dimensions of the gray scale pattern should be approximately one-fourth of the respective picture dimensions. The modulation is adjusted so that the lightest bar corresponds to 15 per cent of the carrier level during the synchronizing peaks and the darkest bar to black level. Black level is defined as 70 per cent of peak-synchronizing amplitude for this test only. The contrast and brightness controls of the receiver are adjusted so that the scanning lines just disappear in the darkest bar and the lightest bar is at maximum focused luminance (Section 3.9). The luminance of each bar is measured with the gray scale pattern centered in the picture. The measurements should be repeated with the gray scale at the sides and corners of the picture and may also be repeated with higher or lower background brightness.

3.14.3 Presentation of Data. The luminance of each bar is plotted against the modulation level expressed as a percentage of the blanking level to peak white amplitude. 8.3 per cent on the abscissa corresponds to black level (70 per cent of the peak-synchronizing amplitude) and 100 per cent corresponds to reference white level (15 per cent of the peak-synchronizing amplitude). Logarithmic scales are used. See Fig. 3.14.3 for typical data.

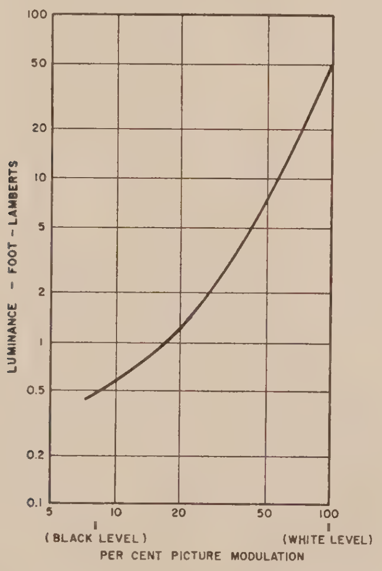


Fig. 3.14.3—Luminance transfer characteristic.

3.15 Interlace

The quality of the interlace is described by the ratio of the distances between one scanning line and the two lines adjacent to it which belong to the interlaced field, each expressed as a percentage of the distance between two consecutive lines in a single field (Fig. 3.15). A test should be made to determine whether the interlace is affected by the vertical hold control, the type of picture modulation, or other control settings, and the results noted in the data.

3.16 Effect of Vertical Synchronizing Pulse on Horizontal Synchronization

Rotation of the horizontal hold control may produce a relative displacement of the upper part of the picture. This effect is described by noting the deformation of a vertical line, as described by δ_1 and δ_2 in Fig. 3.16, as the horizontal hold control is rotated through the pull-in range. The resulting displacements are expressed as a percentage of the picture dimensions:

$$\frac{\delta_1}{w} \times 100 \quad \text{and} \quad \frac{\delta_2}{h} \times 100.$$

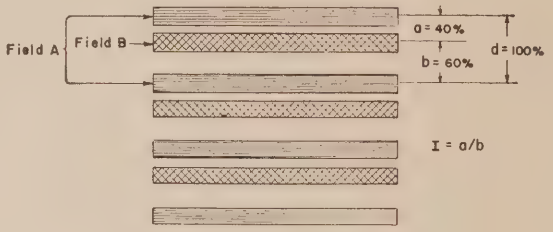


Fig. 3.15—Quality of interlace.

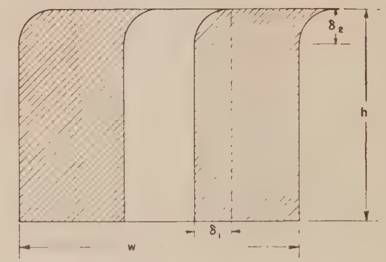


Fig. 3.16—Pulling on vertical synchronizing pulses.

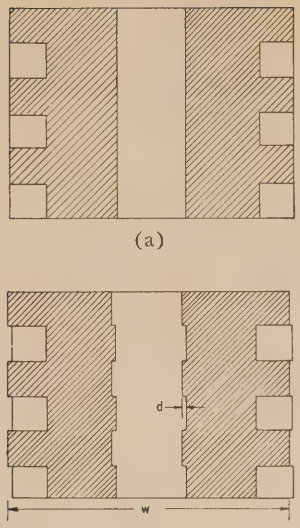
3.17 Effects of Picture Information on Synchronization

Picture information in the form of large area black-to-white transitions frequently has adverse effects on synchronization. These effects may be measured by the use of a test chart as shown in Fig. 3.17(a). The receiver is adjusted as in Section 1.10.5. The resulting displacements [Fig. 3.17(b)] are expressed as a percentage of the picture width:

$$\text{Pulling on picture content} = \frac{d}{w} \times 100.$$

If no displacements result, the synchronizing-signal amplitude is reduced until measurable displacements occur. The data must include a statement of the reduction in synchronizing signal used.

Other test charts than the one shown in Fig. 3.17(a) may be used to advantage. For example, the polarity of Fig. 3.17(a) may be reversed, or the relative black and white areas varied. Due to the subjective nature of these data, the results are best reported as a side-by-side comparison, rather than as absolute data.



(a)

(b)

Fig. 3.17—Effects of picture on synchronization.
(a) Test chart. (b) Typical results.

3.18 Subjective Examination of Picture Quality

Degradations of picture quality which are not described by the tests specified in this standard may be detected by subjectively examining the picture over a wide range of operating conditions. Particular emphasis should be given to the effect of variations in the settings of the receiver controls.

The following types of degradation should be looked for:

a) Luminance irregularities due to extraneous signals at the picture device control electrode, scanning velocity variation, or fold-over.

b) Interference generated internally such as extraneous oscillations in the deflection system (Barkhausen or other retarding field oscillations), shock excitation of incidental resonant circuits by sudden start or cessation of deflection currents, or crosstalk of sound into the picture.

c) Unstable synchronization, characterized as jumping, jittering, rolling, etc.

The above conditions can frequently be described best by a photograph of the phenomenon. When this is not possible, a subjective description of the extent, direction, size, shape, frequency and seriousness of the fault should be given.

Chapter 4—Sensitivity, Picture

4.1 Picture Sensitivity

The sensitivity of the picture channel may be limited either by the available gain or by internal (thermal-agitation) noise originating principally in the tuner.

The "nominal sensitivity" and the "peak sensitivity" describe the extent to which the receiver performance is limited by the available gain. The "noise factor" is a measure of the internal receiver noise.

The nominal sensitivity (Section 4.2) is a measure of the receiver gain when the receiver is tuned normally to produce the nominal picture carrier intermediate frequency.

The peak sensitivity (Section 4.3) is a measure of the receiver gain when the receiver is retuned so that it has maximum gain at the picture carrier frequency. The sound channel performance and the adjacent-channel selectivity under this retuned condition are dependent upon the required amount of retuning of the local oscillator and the amount of shift in the IF amplifier selectivity as a function of AGC voltage.

In actual use, the receiver may be tuned to achieve a compromise between picture sensitivity, sound sensitivity and adjacent-channel rejection, depending on local conditions. This yields an effective value of receiver sensitivity which depends upon how closely the nominal sensitivity approaches the peak sensitivity.

In addition to gain and internal receiver noise, the effective receiver sensitivity is influenced by other characteristics such as weak-signal IF selectivity, transient response, gamma, contrast, luminance, screen persistence, clipping levels, and synchronizing performance.

4.2 Nominal Picture Sensitivity

4.2.1 Definition. The nominal picture sensitivity is the lowest input signal which results in standard picture test output when the receiver is tuned to produce the nominal picture intermediate frequency (Section 1.10.5.2).

4.2.2 Method of Measurement. The picture signal generator is connected to the receiver as described in Section 1.7. Standard white-pattern modulation (Section 1.5.2) is used. The receiver is tuned to produce the nominal intermediate frequency (Section 1.10.5.2) and the receiver controls are adjusted for maximum sensitivity.

The input signal is increased until the standard picture test output (Section 1.8) is obtained. This value is the nominal picture sensitivity.

If the video output is obscured by noise, sufficient filtering should be added so that the blanking level and peak white are delineated.

Where a television signal generator is not available, a 30 per cent sine-wave modulated signal (Section 1.5.1) can be used. This alternative procedure requires that the normal AGC voltage which would be produced by standard white-pattern modulation be simulated. A low-pass filter is used to reject thermal noise, and the input level is adjusted to produce standard test output.

4.2.3 Presentation of Data. The sensitivity is measured on the channels of interest and the results expressed in microvolts or in decibels below 1 volt.

4.3 Peak Picture Sensitivity

4.3.1 Definition. The peak picture sensitivity is the lowest input signal which results in standard picture test output when the receiver is tuned for maximum picture output.

4.3.2 Method of Measurement. The procedure is the same as in Section 4.2.2 except that the receiver is detuned the minimum amount required to produce peak output in the vicinity of the normal tuning position; if the output continues to increase as the receiver is detuned from the normal setting (as defined in Section 1.10.5.2), the peak sensitivity is measured with the receiver tuned so that the intermediate frequency produced is 1.5 mc lower than the nominal value.

4.3.3 Sound Sensitivity. The peak sound sensitivity, as described in Chapter 8, is measured for the same receiver tuning used in measuring the peak picture sensitivity.

4.4 Noise-Limited Sensitivity—Noise Factor

4.4.1 Introduction. Provided a receiver has sufficient gain, its usable sensitivity is primarily limited by its noise factor.[5] The noise factor is a significant and reproducible measure of the noise performance of the input portion of the receiver, as compared with that of an ideal noise-free receiver. Other factors influence the noise-limited sensitivity as described in Section 4.1.

4.4.2 Definition of "Noise Factor (Noise Figure), Average. Of a linear system, the ratio of (1) the total noise power delivered by the system into its output termination when the noise temperature of its input termination is standard (290°K) at all frequencies, to (2) the portion thereof engendered by the input termination. For heterodyne systems, portion (2) includes only that noise from the input termination which appears in the output via the principal frequency transformation of the system and does not include spurious contributions such as those from image-frequency transformations."[6]

4.4.3 Method of Measurement. A random noise generator, which usually consists of a temperature-limited thermionic diode, is employed as a calibrated source of random noise. This noise generator is matched to the nominal 300-ohm input impedance of the receiver.

In order to compare the receiver noise with that of an ideal receiver, the receiver detector is linearized by injecting an auxiliary unmodulated signal at either the signal or the intermediate frequency. The noise factor is then determined by noting the amount of noise which must be added by the noise generator to produce a 3-db increase in the noise measured at the detector output.

The detailed measurement procedure is given below:

a) The test equipment is connected to the receiver.

b) The receiver is tuned as described in Section 4.3 for measuring peak picture sensitivity.

c) The AGC voltage applied to the first amplifier in the receiver is replaced by a fixed bias equal to that existing at the amplifier when the input is connected to a standard dummy antenna, with no applied signal. An adjustable bias source is connected to replace the AGC voltages on the later IF amplifier stages. The AGC voltages normally developed in the receiver should be rendered completely ineffective.

d) The waveform at the output of the video detector is examined with an oscilloscope to establish that only noise is present (no hum or other signals). If it is necessary to disable the vertical or horizontal sweep circuits to eliminate interference, the power supply should be loaded so that operating conditions of the rest of the receiver are normal.

e) A high-impedance video voltmeter is connected across the video-detector output to measure the noise output. If an averaging type of meter is used, precaution should be taken that it does not overload on the upper part of the scale because of the high ratio of peak-to-rms value of the noise voltage. The technique outlined in the following steps must be carefully followed so that the noise peaks are not clipped in the receiver itself. To observe whether nonlinearity is present, the video-detector output should be monitored on the oscilloscope throughout the test.

Care should be taken that no regeneration is introduced as a result of connecting the video voltmeter and the oscilloscope to the output of the detector.

f) An unmodulated carrier at either signal or IF frequency is coupled loosely into the receiver. The signal is tuned to the picture carrier frequency (normally the center of the band for this measurement) and its amplitude is increased to the point that *just* produces maximum output reading on the video voltmeter. This amplitude is the amount required to linearize the detector. The reading on the video voltmeter is then observed.

g) The noise generator is then turned on and its output increased until the noise output meter reading increases 3 db above that of step f). The noise factor is then read from the calibrated noise generator scale. If the noise factor for a 3-db increase in receiver noise output is not indicated directly on the instrument, or if the noise factor of the receiver is beyond the range of the instrument, making it impossible to increase the noise output by 3 db, then the following formula for the noise factor is applied:

$$NF \text{ (in db)} = 10 \log_{10} \frac{20IR_a}{M-1}$$

where

I = dc current through the noise diode,
R_a = noise generator source resistance,
M = relative increase in receiver noise output power.

h) The effect of spurious responses, principally the image response, is usually negligible in television receivers, provided the image rejection is greater than 6 db.

i) The noise factor should be measured as a function of input signal level or alternative means should be used to establish that the noise factor for maximum sensitivity conditions is indicative of the signal-to-noise ratio at higher signal levels. For example, if shorting the AGC bias applied to the tuner improves the signal-to-noise ratio, this indicates that the noise factor is poorer at the higher signal levels.

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[5] This definition is from 57 IRE 7. S2 "Standards on Electron Tubes: Definitions of Terms, 1957," vol. 45, pp. 983–1010; July, 1957.

[6] 53 IRE 7. S1 "Standards on Electron Devices: Methods of Measuring Noise," Proc. IRE, vol. 41, p. 896; July, 1953.

4.4.4 Presentation of Data. The noise factor, for each channel measured, is given in decibels. A statement of whether the signal-to-noise ratio is degraded by the AGC voltage is included [see Section 4.4.3 (i)].

4.5 AGC Characteristic and Figure of Merit

4.5.1 Definition.

4.5.1.1 AGC characteristic. The AGC characteristic describes the dependence of the picture output and the sound output levels on the input signal.

4.5.1.2 AGC figure of merit. The picture AGC figure of merit is the number of decibels reduction of the input signal, below 100,000 μv, required to reduce the picture output voltage by 10 db. The sound AGC figure of merit is defined in the same manner.

4.5.2 Method of Measurement. The picture and sound signal generators are connected to the receiver as described in Section 1.7. Standard white-pattern picture modulation (Section 1.5.2) is used. The sound carrier is modulated 30 per cent at 400 cps. The picture-to-sound carrier ratio is unity.

The receiver is tuned to produce the nominal intermediate frequency (Section 1.10.5.2), and the contrast and volume controls adjusted for standard test output with an input signal of 100,000 μv. The input signal is then varied from 10 μv to 2 volts (if available), without altering the controls, and the picture and sound outputs measured as a function of the input level. The measurement is repeated with the controls adjusted for standard test output with input signals of 10,000 and 1000 μv, as in Fig. 4.5.3.1.

If the video output is obscured by noise, sufficient filtering should be added so that the blanking level and peak white are delineated.

If the receiver has a "local-distance" sensitivity switch, its position should be noted. If the sensitivity or contrast controls significantly influence the operation of the AGC circuit, the measurement should be repeated for appropriate settings of the controls.

4.5.3 Presentation of Data.

4.5.3.1 AGC characteristics. This is plotted as in Fig. 4.5.3.1 for picture and sound outputs.

4.5.3.2 AGC figure of merit. This is noted as in Fig. 4.5.3.1 for both the picture and sound outputs.

4.6 Maximum Usable Input Signal

4.6.1 Definition. The maximum usable input signal is the highest level of input signal for which the receiver gives acceptable performance under specified conditions.

4.6.2 Method of Measurement. The same test conditions are used as in Section 4.5.2.

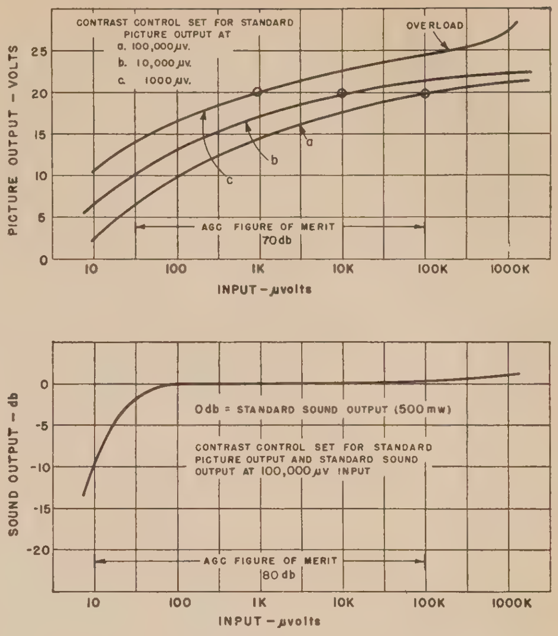


Fig. 4.5.3.1—AGC characteristics for the picture and sound channels.

1) The input level is gradually increased and the receiver controls and switches are adjusted to maintain optimum performance. The highest input signal level for which the performance remains acceptable is noted.

2) The measurement is repeated to find the highest input signal level which will just cause the receiver to operate abnormally (*e.g.*, "lock-out" by AGC blocking) when the channel selector is switched, or when the receiver power is turned on with the input signal applied.

4.6.3 Presentation of Data. The lowest of the values determined in the preceding three tests is recorded with a description of the effect which causes impaired performance.

4.7 AGC Speed

4.7.1 Definition. Amplitude modulation of the composite input signal (airplane flutter) produces amplitude modulation at the picture tube to a degree which depends upon the characteristics of the AGC circuit. The AGC speed is described by a plot of the residual amplitude modulation at the picture tube against the frequency of the amplitude modulation, the per cent modulation of the input signal being maintained at 30 per cent. The AGC speed figure of merit is the frequency at which the per cent modulation of the signal at the picture tube is reduced from 30 per cent to 10 per cent.

4.7.2 Method of Measurement. The picture signal generator is connected to the receiver through an auxiliary RF amplifier, the gain of which can be varied by the application of a sine wave. The percentage modulation is maintained at 30 per cent, while the frequency of modulation is varied from a few cps to several hundred cps. Standard white-pattern modulation (Section 1.5.2) is used. The receiver is tuned to produce the nominal intermediate frequency (Section 1.10.5) and the receiver controls are adjusted for standard test output.

The detector output is observed on an oscilloscope. At each frequency of modulation, the percentage amplitude modulation at the detector output is recorded.

The test is performed at an input level of 3200 μv and 100,000 μv. If the reduction in amplitude modulation percentage is observed to depend significantly on the contrast or AGC controls, the tests are repeated with representative settings of these controls.

4.7.3 Presentation of Data. The amplitude modulation at the picture tube input is plotted against the frequency of the modulation. The AGC speed figure of merit is noted on the curve.

Chapter 5—Interference, Picture

5.1 Introduction

Interfering signals which affect the picture may be generated externally or may be generated by the receiver itself. These undesired signals may enter the receiver through the antenna, the power line, and in some cases, may be picked up directly by the circuit components.

The receiver selectivity characteristics (Section 5.2) indicate the susceptibility of the receiver to undesired signals whose principal path includes the antenna.

Internally generated interference (Section 5.3) can best be measured by observation of the reproduced picture under conditions of controlled input signals.

Separate tests are included for compatibility with color signals (Section 5.4) and the effects of impulse-noise interference (Section 5.5).

5.2 Selectivity Characteristics

5.2.1 Combined Radio-Frequency and Intermediate-Frequency Selectivity Characteristic.

5.2.1.1. Definition. The combined radio-frequency and intermediate-frequency selectivity characteristic is a measure of the relative gain vs frequency from antenna to video detector.

5.2.1.2 Method of measurement. It is desirable to take data under various conditions of receiver gain in order to show possible effects of regeneration and circuit detuning. Since the automatic gain-control circuits are disabled for this measurement, the desired receiver gain conditions are selected initially and the corresponding RF and IF gain-control voltages are measured. The following conditions of receiver gain are suggested:

a) Gain at nominal sensitivity level (Section 4.2.1).

b) Gain with input signal 20 db above nominal sensitivity level.

c) Gain at standard mean-signal level.

The procedure described in Section 4.2.2 is followed and the RF and IF gain-control voltages are measured and recorded for the picture carrier input levels referred to in a), b), and c) above.

The picture carrier modulation is then changed to 30 per cent 400-cps modulation. The gain-control circuits are disabled and RF and IF biases, as determined in the previous measurement at the nominal sensitivity level, are provided from an external source such as a battery. The contrast control remains at its maximum setting for the remainder of the measurements.

The signal generator, with just enough output to give a readable indication at the picture tube, is varied in frequency over the pass band and set at the trap frequency of highest attenuation. At this frequency, the signal generator output is adjusted to give a selected reference level at the picture tube. This reference level should be as high as possible without encountering overload.

The output indicating device may be an oscilloscope or a voltmeter. A 400-cps band-pass filter will prevent thermal noise or hum from affecting the readings.

The signal generator frequency is then varied over the pass band of the receiver and data are taken at enough points to define the selectivity characteristic. At each frequency of measurement, the input level is adjusted to give the previously selected reference output at the picture tube and this input level is recorded.

This procedure is repeated for the receiver gain conditions of b) and c) above with the gain-control biases adjusted to the appropriate values. The same reference output level is used for the three sets of measurements. When making the measurements at reduced receiver gain, it may not be possible to obtain data at the trap frequencies due to overload of the RF or IF circuits.

Because the selectivity is normally measured at an abnormally low detector level to prevent overload, it is desirable to make an additional test to determine whether the response in the pass band changes significantly with detector level.

The selectivity characteristic should be measured on at least one of the standard VHF and one of the standard UHF test channels (Section 1.3).

5.2.1.3 Presentation of data. The combined radio-frequency and intermediate-frequency selectivity characteristic of the receiver is plotted as in Fig. 5.2.1.3.

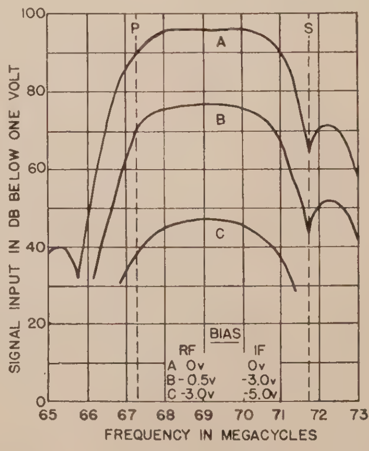


Fig. 5.2.1.3—Typical RF-IF selectivity characteristic.

5.2.2 Intermediate-Frequency Selectivity Characteristic.

5.2.2.1 Definition. The intermediate-frequency selectivity characteristic is a measure of the selectivity of the receiver circuits from the converter input to the video detector.

5.2.2.2 Method of measurement. The procedure of Section 5.2.1.2 is repeated with the signal generator tuned to the intermediate-frequency range and connected to the converter input instead of to the antenna. Measurements are made for the same receiver gain conditions as in Section 5.2.1.2 and the same reference output level is used.

Precautions must be taken to prevent feedback as a result of the signal generator connection.

5.2.2.3 Presentation of data. The intermediate-frequency selectivity is plotted as in Fig. 5.2.1.3 with the appropriate change in the frequency scale.

5.2.3 Rejection of Predictable Off-Channel Signals.

5.2.3.1 Introduction. A television receiver, tuned properly to a desired channel, is subject to interference from a number of specific signals having predictable frequencies. Interference from these signals occurs often enough to warrant individual measurements of the ability of the receiver to reject these specific frequencies. The following measurements are usually made:

1) Lower-Adjacent-Channel Sound-Carrier Rejection Ratio
2) Upper-Adjacent-Channel Picture-Carrier Rejection Ratio
3) Accompanying-Sound-Carrier Rejection Ratio
4) Intermediate-Frequency Rejection Ratio
5) Image Rejection Ratio.

The rejection ratios are ratios of the over-all gain of the receiver at the desired picture carrier frequency to that at the interfering signal frequency of interest.

5.2.3.2 Method of measurement. The test conditions for these measurements are the same as those described in Section 5.2.1.2 except that here the relative gain of the receiver is measured at the picture carrier frequency and at the interfering signal frequency of interest only (as enumerated in Section 5.2.3.1).

In the case of intermediate-frequency and image rejection ratios, the measurements of gain are made at the frequencies within the intermediate- and image-frequency ranges which produce the greatest receiver output.

The intermediate-frequency rejection ratio is usually made for both balanced and unbalanced signal input conditions as follows:

Balanced Input. The signal generator is connected to the receiver through the standard dummy antenna (Section 1.7).

Unbalanced Input. The intermediate-frequency signal is applied unbalanced to the receiver antenna terminals as shown in Fig. 5.2.3.2. However, the desired picture carrier signal is applied balanced through the standard dummy antenna. The unbalanced input voltage is the voltage across the resistor at the output of the resistive pad. When making the unbalanced connection, one should connect the generator ground terminal to a receiver ground terminal which is as near as possible to the antenna connections to the tuner.

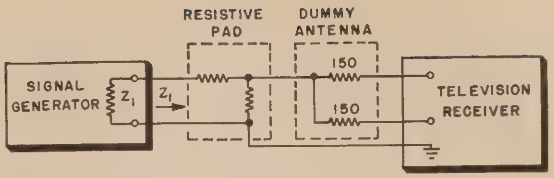


Fig. 5.2.3.2—Connections for unbalanced intermediate-frequency interference ratio measurement.

These rejection ratio measurements are normally made at the receiver gain setting corresponding to nominal sensitivity level.

The measurements should be made on at least one of the standard VHF and one of the standard UHF test frequencies.

5.2.3.3 Presentation of data. The ratio of the input signal level at the interfering frequency of interest to that at the desired picture carrier frequency is expressed in decibels.

5.2.4 Spurious Responses.

5.2.4.1 Introduction. In addition to the interfering signals described in Section 5.2.3, there are other frequencies at which interfering responses may occur. Spurious responses can be caused if external signals or one of their harmonics in combination with the receiver local-oscillator frequency or one of its harmonics produce an interfering signal in the intermediate-frequency pass band. Spurious responses may also be caused by cross modulation.

Because of the extreme frequency range involved, it is generally impractical to test for all possible spurious responses. The test described in Section 5.2.4.2 specifies a limited frequency range which is adequate to cover most of the possibilities likely to be encountered.

In general, the interfering signals existing at the lower end of the frequency range specified in Section 5.2.4.2 will appear as unbalanced signals at the receiver input terminals, while those at the higher end appear as balanced signals. Because the balanced or unbalanced signal condition is a function of many unpredictable factors, the test specifies that measurements be made for both conditions.

5.2.4.2 Method of measurement. For this test a signal source capable of supplying a harmonic-free interfering signal output from 10 μv to at least 2.0 volts is required. This source should cover the frequency range of 0.5 to 1000 mc. To fulfill these requirements, more than one generator may be necessary, and low-pass filters may be required to attenuate harmonics.

The interfering signal generator and the picture and sound signal generator are applied to the receiver in balanced connection through the dummy antenna described in Section 1.7.3. The resolution chart is applied as modulation to the picture signal generator, standard sound modulation is applied to the sound generator, and the interfering signal generator is amplitude-modulated 30 per cent at 1000 cycles. The picture and sound signal generators are adjusted for an input approximately 10 db above the nominal sensitivity input (Section 4.2), the receiver is adjusted for normal operation, and the interfering signal generator is set at maximum output.

The frequency of the interfering signal is varied over the range from 0.5 to 1000 mc while the picture is under observation. Any interference to either picture or sound should be noted together with the frequency at which it occurs. If any interference is noted, the interfering signal level at that frequency is reduced until the interference is just perceptible and this signal level is noted.

The test should be repeated with the picture and sound signal input 10 db below the maximum usable input level (Section 4.6).

These tests should be repeated with the interfering signal applied in the unbalanced connection, as shown in Fig. 5.2.4.2.

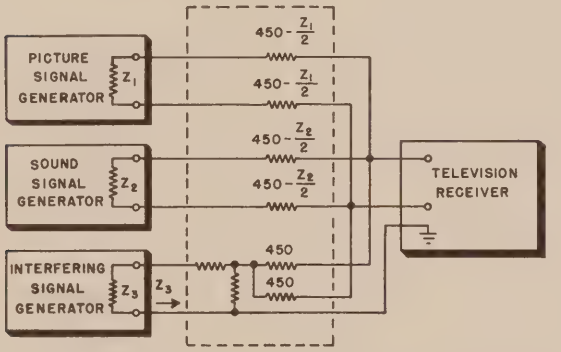


Fig. 5.2.4.2—Generator connections for unbalanced-input spurious-response measurement.

5.2.4.3 Presentation of data. The ratio between the interfering and desired signals in decibels is tabulated where the interference for the condition is just perceptible. The frequency of the interfering signal, the channel to which the receiver is tuned, the level of the desired signal, and the type of interference are noted.

5.3 Internally Generated Interference

5.3.1 Radio-Frequency and Intermediate-Frequency Harmonic Interference.

5.3.1.1 Definition. 1) In a television receiver tuned to accept an RF signal which is a harmonic of the intermediate frequency, the harmonics generated by the IF amplifier may be of sufficient amplitude to be reamplified by the tuner and mixed with the desired RF signal. A beatnote having a frequency equal to the difference between the desired RF carrier and the IF harmonic is produced. If this beat frequency lies within the receiver video pass band, it can be observed on the picture tube screen. This is intermediate-frequency harmonic interference, sometimes referred to as "tweets," and is usually more troublesome with weak input signals.

2) Picture interference may also be caused by harmonics of the desired input signal mixing with harmonics of the local oscillator and producing signals that fall within the intermediate-frequency pass band of the receiver. This interference is more likely to appear with strong input signals.

5.3.1.2 Method of measurement. The picture and sound carrier generators are connected through the standard dummy antenna to the receiver. The picture modulation consists of standard white-pattern modulation and the sound generator is unmodulated. The receiver is adjusted for normal operation.

Observations are made on an oscilloscope connected to the picture tube input. The signal input levels are varied from 10 μv to the maximum usable signal input level (Section 4.6), and the input level and receiver tuning for the most objectionable interference within the usable (neglecting the tweet) picture range are noted. At this level, the peak-to-peak beat output during the picture interval and the blanking level to peak white amplitude are measured.

5.3.1.3 Presentation of data. The peak-to-peak beat output is expressed as a percentage of the blanking level to peak white output and recorded with the input signal level for the channels of interest. Where a subjective evaluation is necessary, a description of the perceptibility of the beat and the effect of receiver tuning should be included with the pertinent test conditions.

5.3.2 Sound into Picture

5.3.2.1 Definition. This type of interference is a result of either the coupling of the sound modulation or 4.5-mc intercarrier signal from the sound channel circuitry to the video circuitry, or intermodulation between sound and picture carriers in the RF or IF circuits. The result is an undesired pattern on the picture tube screen.

5.3.2.2 Method of measurement. The sound and picture signal generators, at standard mean-signal input, are connected to the input of the receiver (Section 1.7.3). The receiver is tuned and adjusted for normal operation (Section 1.10.5). White-pattern modulation (Section 1.5.2) is applied to the picture carrier generator and 100-cps modulation is applied to the sound carrier generator at maximum system deviation. The receiver volume control is adjusted for standard test output (Section 1.9). The speaker should be electrically connected to the receiver and in its normal position with respect to the receiver chassis. The signal source must be free of cross modulation between picture and sound signals.

The sound-to-picture carrier ratio is then increased from unity, maintaining the picture carrier constant, until 100-cps bars are just perceptible on the picture tube screen and the corresponding value of sound-to-picture carrier ratio is recorded.

The test should be repeated with sound modulation removed, and the sound-to-picture carrier ratio increased until the effect of the sound carrier becomes visible in the form of a fine-grain 4.5-mc beat pattern. The corresponding sound-to-picture carrier ratio is recorded.

The preceding tests should be repeated at maximum usable input signal to detect cross-modulation effects.

With unity sound-to-picture carrier ratio at standard mean-signal level, the volume control is advanced until interference is again observed. The power output at which this occurs is noted.

5.3.2.3 Presentation of data. The sound-to-picture carrier ratio in decibels which results in just perceptible interference, together with the picture carrier level, is tabulated for the tests described in Section 5.3.2.2. The sound power output corresponding to just perceptible interference is also noted.

5.3.3 Interference from Horizontal Deflection Circuits.

5.3.3.1 Introduction. This interference is usually caused by bursts of RF energy generated in the horizontal deflection system and coupled into the signal circuits at either the incoming signal frequency or intermediate frequency. The visual effects usually consist of a vertical bar in the picture or horizontal synchronization instability, or both. The interference may appear on one or more channels and is usually more severe at weak signal input levels.

5.3.3.2 Method of measurement. The receiver is tuned to a channel where the interference is noted. The appropriate picture carrier signal with white-pattern modulation (Section 1.5.2) is connected to the receiver through the dummy antenna, and the receiver is tuned normally. The transmission line to the tuner should be in its normal position for this measurement since the results are affected by the location (and the balance) of the input system.

The level of the picture carrier signal is then gradually increased until the interference is no longer perceptible. This signal level is recorded. The test should be repeated for all channels where the interference is noted.

5.4 Compatibility with Color Signal

5.4.1 Introduction. The purpose of this test is to determine subjectively whether the monochrome receiver under test is capable of receiving a color signal without producing undesirable beatnote patterns in the picture.

5.4.2 Method of Measurement. For this test a laboratory-generated color signal is required. The picture and sound carrier signals at standard mean-signal level are connected to the receiver. Standard sound test modulation is applied to the sound carrier and the picture carrier is modulated with video information corresponding to a color bar pattern. It is desirable to have full-purity (or "saturated") color bars corresponding to each of the primary colors as well as the complementary colors, and in addition one white bar. The white bar is transmitted as a peak white signal at full intensity, and the color bars are transmitted at 75 per cent of their maximum possible amplitude in order to avoid over-modulation effects on certain colors. These levels are chosen as representative of the most severe conditions ordinarily found in natural scenes.

With the receiver controls adjusted for normal operation, the picture is observed in each of the bar areas for the presence of spurious patterns resulting from the 3.58-mc chrominance signal, or a 920-kc beatnote between the chrominance signal and the sound carrier. Effects of variations in the tuning should also be noted.

The test should be repeated with the sound carrier level maintained at twice the picture carrier level. A check should be made to determine whether the results vary significantly with signal level.

5.4.3 Presentation of Data. The presence of a 3.58-mc or a 920-kc beat should be recorded, together with the corresponding input signal conditions. The effect of variations in the receiver tuning control should also be noted.

5.5 Impulse Noise Interference Susceptibility

At present no instrument is available which closely simulates the interference generated by automobile ignition systems, vibrators, shavers, and similar sparking devices. Lacking such equipment, receiver performance under impulse-noise conditions is usually evaluated by making comparative performance tests using an actual noise source coupled to the receiver input.

The receiver under test and the comparison receiver are placed in a shielded room and connected through a dummy-antenna network so as to receive equal signals. The noise source is mounted outside the shielded room and coupled to the single cable which feeds both receivers.

The receivers are adjusted for normal operation using standard test-pattern picture modulation and standard sound modulation. Initial tests are made at a level 10 db above nominal sensitivity level.

The susceptibility of the receiver is tested by observing the performance as the interference input level is increased. Observations should be made for the following defects:

a) Disturbance of the luminance during and immediately after the interfering pulses. Note should be made of whether the interference is predominantly black or white, the duration of the interference, the presence of blocking, and AGC disturbance.

b) Disturbance of the horizontal synchronization.

c) Disturbance of the vertical synchronization.

d) Disturbance of the sound output.

The relative performance of the receiver under test with respect to the comparison receiver is described. The observations are repeated at various input signal levels and with various types of noise sources.

Chapter 6—Electrical Fidelity, Picture

6.1 Introduction

The electrical fidelity is the over-all response of the receiver to the electrical variations which make up the signal present at the picture tube input. This involves two broad characteristics:

One is the ability of the receiver circuits, as the scanning spot travels horizontally, to reproduce a transition representing an abrupt change from black to white (or vice versa) and to resolve fine horizontal detail. This ability is dependent on the amplitude and phase response of the receiver to frequencies above 100 kc. In a monochrome receiver the phase response need not be measured directly since adequate information may be obtained from measurement of the amplitude response (Section 6.3) and the step response (Section 6.4).

The other characteristic is the ability to reproduce the electrical variations which correspond to the shading in the picture. This involves the response to frequencies down to the field repetition rate. The information may be obtained by observing the low-frequency square-wave response (Section 6.5) at both the field rate and the line rate.

6.2 General Measuring Techniques

6.2.1 Picture Signal Generator. The signal source for measuring the electrical fidelity must have sufficiently low distortion so as not to interfere with the receiver measurements. In addition to the test modulation, the picture carrier should be provided with composite sync modulation. This is desirable so that the AGC, sync, and dc restorer circuits function normally. If composite sync modulation is not used, these circuits should be biased in such a way that the normal picture signal response is not distorted. For additional requirements of the picture signal generator, refer to Section 2.1.

6.2.2 Vestigial-Sideband Filter. To exactly simulate the television broadcast transmission characteristic requires the use of a vestigial-sideband filter. However, most receivers have sufficient selectivity so that this relatively complex filter can normally be omitted with negligible distortion of the amplitude response and the step response.

6.2.3 Standard Envelope-Delay Predistortion Network. To simulate television broadcast transmissions, a standard envelope-delay predistortion network (Fig. 6.2.3) is inserted ahead of the modulation input of the picture signal generator. (This network is designed to compensate for the high-frequency phase distortion introduced by the relatively sharp cutoff in the picture IF amplifier of color receivers.)

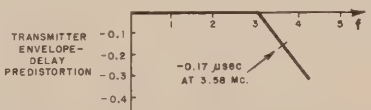


Fig. 6.2.3—Response of the standard transmitter envelope-delay predistortion network.

6.2.4 Receiver Input Connections. The output of the picture signal generator is supplied to the receiver as described in Section 1.7.

6.2.5 Selection of RF Channel. The measurements are normally made on a single channel having a relatively flat RF response.

6.2.6 Receiver Tuning. The receiver must be carefully tuned. If the tuning differs from that in Section 1.10.5.2, the tuning criterion should be described in the data.

6.2.7 Signal Input Level. The standard mean-signal input level is used.

6.2.8 Picture Signal Generator Modulation. The picture signal generator modulation is specifically described for each of the three measurements in Sections 6.3.2, 6.4.2, and 6.5.2.

6.2.9 Test Output Level. The nominal test output level is the standard picture test output (Section 1.8). However, other levels may be used where the modulation percentage or the contrast control has a significant effect on the response.

6.2.10 Adjustment of Receiver Controls. The receiver controls are adjusted for normal operation. In each of the measurements the effect of the contrast control on the response should be observed and, where significant, measurements should be repeated for representative settings of this control. The brightness control should be adjusted for normal operation for each of these contrast control settings so that picture tube overload will not distort the response. Where overload occurs in the video amplifier, it may be necessary to reduce the percentage of the picture signal modulation. Deviations from the specified measuring conditions should be included in the data.

6.2.11 Oscilloscope Connection. The response at the input of the picture tube is observed using a wide-band oscilloscope (Section 2.5). A probe having negligibly small input capacitance may be used; alternatively, the picture tube may be disconnected and its capacitance replaced by that of the oscilloscope in such a way as not to alter the original response.

6.3 Amplitude Response

6.3.1 Definition. The amplitude response is the sine-wave modulation-frequency response characteristic at the picture tube input as a function of the modulation frequency.

6.3.2 Method of Measurement. The picture signal generator is modulated with a composite sync signal and a sine-wave picture signal as shown in Fig. 6.3.2. The sine-wave modulation frequency is varied between 100 kc and 4.5 mc while maintaining the modulation constant at the level where the peaks of the sine waves correspond to 15 per cent and 70 per cent of the synchronizing signal peaks. A video sweep generator may be used for this modulation.

The receiver contrast control is adjusted for standard picture test output at the input of the picture tube for the lowest modulation frequency (100 kc). Where contrast control settings have a significant effect on the response, the response should be measured at several

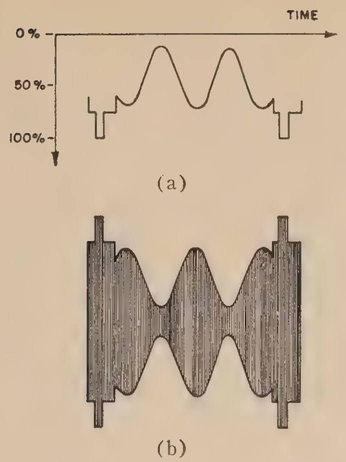


Fig. 6.3.2—Sine-wave picture signal used for measuring the amplitude response. (a) Picture-tube signal. (b) Modulated RF picture signal.

representative settings, observing the precautions of Section 6.2.10.

The amplitude response may be dependent on the percentage modulation of the sine-wave picture signal. If the response is observed to change significantly as the percentage modulation is reduced, the measurement should be repeated with the modulation of the sine-wave envelope reduced by 6 db.

6.3.3 Presentation of Data. The amplitude of the sine wave at the input to the picture tube is plotted as a function of the modulation frequency as shown in Fig. 6.3.3.

6.4 Step Response

6.4.1 Definition. The step response is the waveform measured at the picture tube input when the picture modulation is a rectangular pulse having sufficient duration for steady-state to be reached.

6.4.2 Method of Measurement. The standard picture signal generator is modulated with a rectangular pulse and composite sync [Fig. 6.4.2(a)]. The rectangular pulse is synchronized to the line scanning frequency and phased so as to produce a black vertical bar. The step response is described by the waveform at the picture tube input corresponding to the black-to-white and white-to-black transitions. This contains the desired information on rise time, overshoot, ringing, smear, etc., as defined by Fig. 6.4.2(b). (This differs considerably from a typical receiver response.)

The step response may be dependent on the percentage modulation. If the response is observed to change significantly as the percentage modulation is reduced, the measurement should be repeated with the modulation reduced by 6 db.

When the contrast control is observed to have a significant effect on the step response, the measurement should be repeated for representative settings of the contrast control.

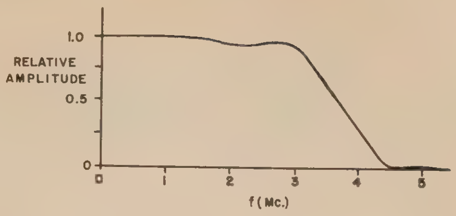


Fig. 6.3.3—Over-all receiver amplitude response.

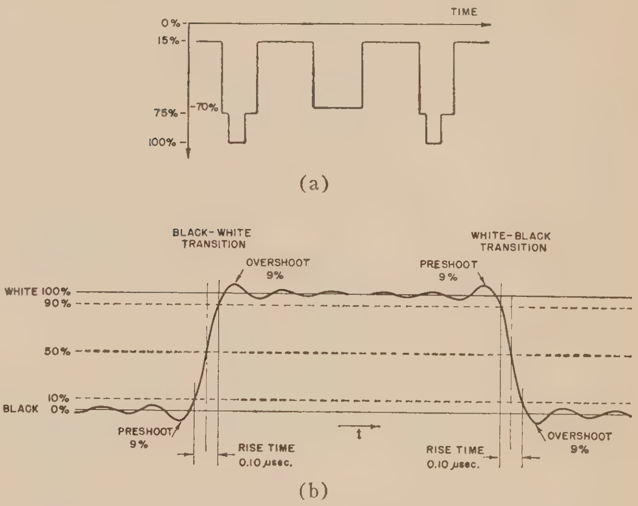


Fig. 6.4.2—(a) Rectangular pulse modulation for step-response measurement. (b) Nomenclature for specification of high-frequency square wave (response shown is that of ideal band-pass filter with rectangular cutoff).

6.5 Low-Frequency Square-Wave Response

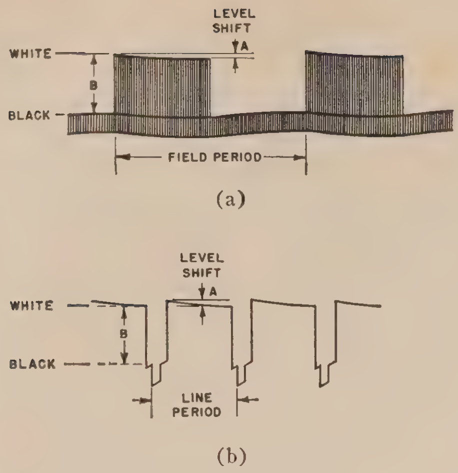
6.5.1 Definition. The low-frequency square-wave response is the waveform produced at the picture tube input, at the field rate and the line rate, when the input signal modulation corresponds to a pattern the lower half of which is black and the upper half white.

6.5.2 Method of Measurement. The picture signal generator is modulated with white at 15 per cent and black at 70 per cent of the peak of sync. The waveform at the picture tube input and the level shift are observed as in Fig. 6.5.2.

Frequently measurement of the low-frequency square-wave response is complicated by the presence of other low-frequency voltage components at both the grid and cathode of the picture tube, including blanking components. In such instances, the resultant output waveforms must be determined with due consideration for these components.

Hum voltages associated with the power supply may lead to errors in the measurements. These can be identified by operating the receiver from a supply which is asynchronous with the field frequency.

6.5.3 Presentation of Data. The low-frequency square-wave responses, including the white-level shift, are shown as in Fig. 6.5.2(a) for the vertical rate, and Fig. 6.5.2(b) for the horizontal rate. Significant power supply hum components should be noted.



(a)

(b)

LEVEL SHIFT PERCENTAGE = $\frac{A}{B} \times 100$

Fig. 6.5.2—(a) White-picture level shift during the field period, and (b) same but during the line period.

6.6 *Electrical Transfer Characteristic*

The electrical transfer characteristic may be plotted following a procedure similar to that described in Section 3.14 for measuring the luminance transfer characteristic.

Chapter 7—Stability

7.1 *Stability of Local Oscillator*

7.1.1 Introduction. These tests are designed to show variations in the frequency of the local oscillator of a television receiver resulting from receiver warm-up and changes in line voltage and signal input level.

7.1.2 Warm-up Drift.

7.1.2.1 Introduction. The local-oscillator frequency usually varies with time for a period following receiver turn-on because of slight changes in component values and tube characteristics with rising temperatures. Ideally, this test is made under controlled humidity conditions and a statement of the existing humidity is included with the test data.

7.1.2.2 Method of measurement. Local-oscillator frequency drift can be measured by measuring the variation of the intermediate frequency produced in the receiver when receiving a stable RF signal. If a suitable frequency counter is available, the intermediate frequency is measured directly at the output of the IF amplifier.

Lacking a frequency counter, the measurement may be made by injecting a signal into the IF amplifier from a stable signal generator covering the intermediate-frequency range. The beatnote produced is monitored at the picture tube and measurements are made by reading the signal generator frequency required to maintain zero-beat output.

The RF picture signal is applied at standard mean-signal input on one of the standard test frequencies.

The receiver is turned on and the fine tuning control is quickly adjusted to place the produced IF signal at the nominal picture intermediate frequency of the receiver. In taking the succeeding measurements of local-oscillator drift with time, the fine tuning control is left untouched.

Frequency readings should be started at one minute after turning on the receiver and continued at suitable intervals until the frequency is stabilized.

The test should be repeated for all channels of interest, always allowing sufficient time for the receiver to cool off completely.

7.1.2.3 Presentation of data. Curves of local-oscillator frequency drift with time are plotted as in Fig. 7.1.2.3.

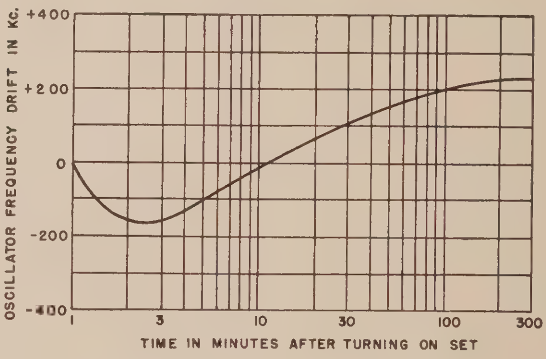


Fig. 7.1.2.3—Local-oscillator warm-up frequency drift characteristic.

7.1.3 Drift with Line-Voltage Variation.

7.1.3.1 Method of measurement. The procedure used to measure drift with line-voltage variation is similar to that described in Section 7.1.2.2. Before this test is begun, however, the receiver should have been in operation long enough to reach temperature stability as determined in Section 7.1.2.2. The fine tuning control is adjusted to produce the nominal oscillator frequency at a line voltage of 117 volts.

The deviation from nominal oscillator frequency is read as the line voltage is varied in 5-volt steps from 105 to 130 volts. Allowance of approximately half a minute should be made after shifting the line voltage so that the cathode temperature stabilizes.

The test should be repeated for all channels of interest.

7.1.3.2 Presentation of data. Curves of frequency drift vs line voltage are plotted as in Fig. 7.1.3.2.

7.1.4 Drift with Variation in Signal Input Level.

7.1.4.1 Introduction. Variations in signal input level may affect the oscillator frequency indirectly by way of the automatic-gain-control circuit. Because of the internal power-supply impedance, variations in AGC voltage may significantly change the dc voltage applied to the oscillator circuit.

7.1.4.2 Method of measurement. The measurement procedure used is similar to that described in Section 7.1.2.2 except that the receiver should have reached

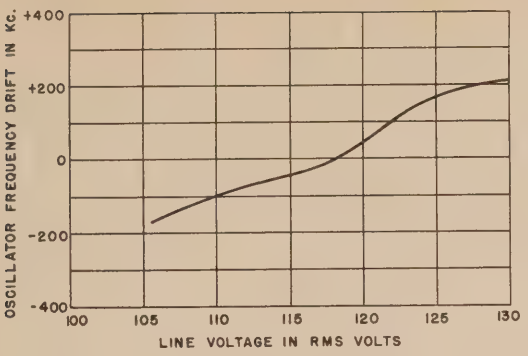


Fig. 7.1.3.2—Local-oscillator frequency drift with line-voltage variation.

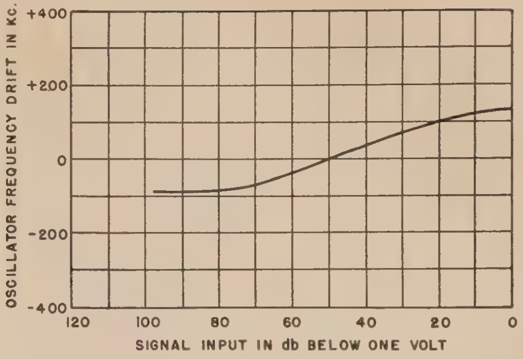


Fig. 7.1.4.3—Local-oscillator frequency drift with signal-input level variation.

temperature stability before readings are taken. The fine tuning control is adjusted to produce the nominal oscillator frequency at a line voltage of 117 volts.

Readings of deviations from nominal oscillator frequency are made as the signal input level is varied from 10 μv to 1 volt.

7.1.4.3 Presentation of data. Curves of local oscillator frequency drift vs signal input level are plotted as in Fig. 7.1.4.3.

7.2 Stability of Deflection Synchronization

7.2.1 Range of Hold Controls.

7.2.1.1 Introduction. It is necessary in the case of automatic-frequency-controlled oscillators to differentiate between pull-in range and hold-in range. Hold-in range is the range of applied frequencies over which the oscillator will hold synchronism once it is synchronized. Pull-in range is the range of applied frequencies over which the oscillator will pull into synchronism as the signal is initially applied. The hold-in range is greater than the pull-in range. Operation of scanning systems beyond the pull-in range but within the hold-in range is normally not satisfactory, since any momentary interruption in the signal will cause the receiver to lose synchronism. Pull-in range is, therefore, the important factor.

With vertical synchronizing circuits, which are usually triggered, the hold-in and pull-in ranges are substantially equal.

7.2.1.2 Method of measurement. For pull-in range measurements, the picture carrier with white-pattern modulation (Section 1.5.2) is applied through the standard dummy antenna to the receiver. The receiver is tuned as described in Section 1.10.5.2. Measurements are made at nominal picture sensitivity level (Section 4.2), standard mean-signal input level, and maximum usable signal level (Section 4.6). The contrast control is set for standard picture test output.

7.2.1.2.1 Horizontal pull-in range. The horizontal hold control is used to throw the receiver out of horizontal synchronism and then is slowly returned to the position where the picture just returns to synchronization. The frequency of the scanning oscillator, just before pull-in occurs, is measured. This measurement is made with the hold control moving in from both sides of center frequency, and the difference of these two frequencies is the horizontal pull-in range.

7.2.1.2.2 Vertical pull-in range. The vertical hold control is used to throw the receiver out of vertical synchronism, and then returned slowly to the position where the picture just returns to synchronization. The synchronizing voltage is then removed from the vertical oscillator, permitting it to free-run, and the frequency of the vertical oscillator is measured. The measurement should be repeated for the other setting of the hold control where synchronization just takes hold. When removing the synchronizing voltage care must be taken that the frequency-determining circuits of the oscillator are not affected.

7.2.1.3 Presentation of data. The frequency difference between the two extremities of the pull-in range is tabulated for the horizontal and vertical pull-in measurements together with the signal input level at which the measurement is made.

7.2.2 Scanning Oscillator Stability.

7.2.2.1 Introduction. These stability tests are designed to show variations in the frequencies of the horizontal and vertical scanning oscillators resulting from receiver warm-up and variations in line voltage.

7.2.2.2 Warm-up drift.

7.2.2.2.1 Method of measurement. For these measurements the synchronizing channel of the receiver is suitably disabled so as to allow the scanning oscillators to run free. An RF input signal is not required for this test but care should be taken that any stray input signals do not change during the measurement.

Frequency measurements of the horizontal and vertical scanning frequencies are made by means of a frequency counter. Alternatively, oscilloscope Lissajous patterns using a calibrated audio-frequency generator and loosely coupled signals from the horizontal and vertical scanning circuits can be used. These measurements are made for the same time interval described in Section 7.1.2.2.

7.2.2.2.2 Presentation of data. The horizontal and vertical scanning oscillator warm-up drifts are plotted as in Fig. 7.1.2.3 with the appropriate changes of the frequency scale.

7.2.2.3 Drift with line-voltage variation.

7.2.2.3.1 Method of measurement. The procedure used to measure scanning oscillator drift with line-voltage variation is similar to that described in Section 7.2.2.2.1 except that the frequency readings are taken as a function of line voltage. The line voltage is varied in 5-volt steps from 105 to 130 volts.

Before this test is begun, the receiver should have reached temperature stability as determined in the measurement of Section 7.2.2.2.1.

7.2.2.3.2 Presentation of data. The horizontal and vertical scanning oscillator frequency drifts are plotted as in Fig. 7.1.3.2 with appropriate changes of the frequency scale.

7.2.3 Static Phase Accuracy of AFC Loop.

7.2.3.1 Definition. The static phase accuracy is a measure of the change in relative phase between input and output of the AFC loop which accompanies a change in either input frequency or local-oscillator frequency.

7.2.3.2 Method of measurement. To measure the static phase accuracy, a picture signal generator, modulated with the resolution chart and having an output amplitude equal to standard mean-signal input level, is applied through the dummy antenna (Section 1.7) to the receiver. The receiver is tuned according to Section 1.10.5. The contrast control is adjusted for standard test output.

The horizontal hold control is moved first clockwise and then counterclockwise to the extremes of the pull-in range as defined in Section 7.2.1. The location of a fixed point of the test pattern is observed on the picture-tube screen and the horizontal displacement of this point is measured as the horizontal hold control is moved through the pull-in range. The static phase accuracy in degrees per cycle per second is given by

$$\frac{\text{Observation Point Displacement (inches)} \times 360 \text{ (degrees)}}{1.15 \times \text{Trace Width (inches)} \times \text{Pull-InFrequency Range (cps)}}.$$

The factor 1.15 in this equation allows for a retrace time of 13 per cent. Trace width refers to the length of horizontal travel of the forward trace of the electron beam. If the scanning width is so great that the picture tube is overscanned, the trace width should include that portion of the trace which lies beyond the edge of the picture tube.

7.2.4 Phase Step Response of AFC Loop.

7.2.4.1 Definition. This test is a measure of the response of the horizontal AFC loop system to a step of input phase. This response is indicative of the system's ability to integrate the incoming synchronizing information over a given period of time. Systems with the same step response will, in general, show comparable performance under the influence of random noise.

7.2.4.2 Method of measurement. Method 1: The horizontal synchronizing signal is phase-modulated at the sync generator with a 30-cps square wave synchronized with the sync generator. The receiver is synchronized both horizontally and vertically and is adjusted for best linearity. The horizontal hold control is set at the center of its pull-in range. A stationary video pulse is transmitted during each horizontal line so that a vertical white line appears in the center of the picture tube screen when the phase modulation is removed from the synchronizing signal. With the phase modulation applied, the white line traces the positive and negative step response of the AFC loop on alternate fields as a stationary pattern on the picture tube screen. In this display the vertical axis is the time axis and the horizontal axis displays the output phase amplitude. A special signal generator has been developed for this test and is described by Gruen.[7] In this method, the synchronizing signal, but not the video pulse, is phase-modulated. To insure linear operation of the AFC loop, the phase-modulation amplitude should not exceed ±30 degrees.

A typical step response is shown in Fig. 7.2.4.2. Rep-

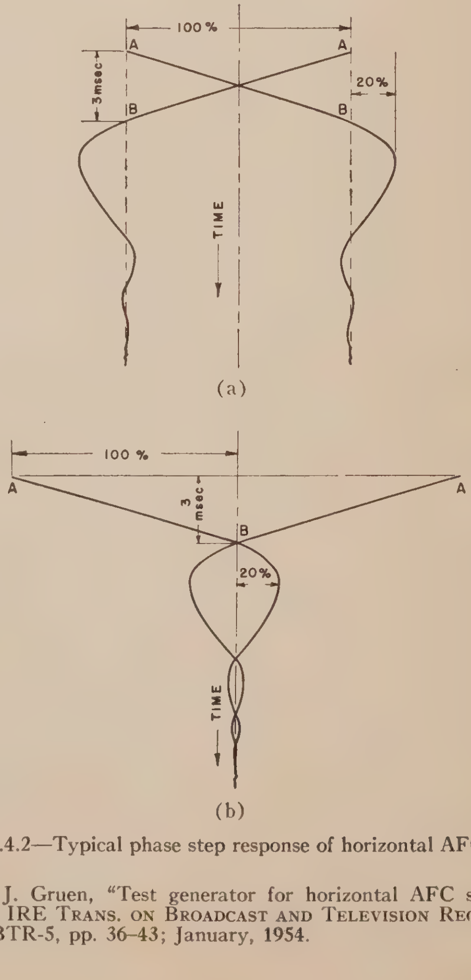


Fig. 7.2.4.2—Typical phase step response of horizontal AFC loop.

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[7] W. J. Gruen, "Test generator for horizontal AFC scanning system," IRE TRANS. ON BROADCAST AND TELEVISION RECEIVERS, vol. PGBTR-5, pp. 36–43; January, 1954.

resentative ranges of values of overshoot are 15–25 per cent, and of rise time from the start of the transient to the first crossover (point *A* to point *B*) are 2–4 msec. The start of the transient should be smooth as shown in the figure; an abrupt change at this point is indicative of direct sync getting into the horizontal oscillator.

Method 2: If the composite sync generator of the picture-signal generating equipment is accessible, a 30-cps square wave may be introduced into the reactance tube of the sync generator to obtain the desired phase modulation. (The sync generator's 31.5-kc oscillator should operate as a locked oscillator controlled by a fixed frequency.) With this method, both the video and sync signals are phase-modulated.

7.2.4.3 Presentation of data. The results of this measurement consist of photographs of, or plots derived from, the picture-tube screen and will be of the form of Fig. 7.2.4.2.

7.2.5 Interference Affecting Synchronization. Receivers are tested for vulnerability to impulse-noise interference as described in Section 5.5.

It is possible for picture or sound information to affect the synchronization. This is checked by subjecting the receiver to a wide range of operating conditions, including operation at minimum and maximum contrast, high brightness, high sound output, etc.

Any impairment of synchronization is reported along with a description of the test conditions.

Part III—SOUND SECTION OF THE RECEIVER

Chapter 8—Sensitivity

8.1 General

This section includes procedures for the measurement of the over-all performance of the sound channel. Receivers employing a separate sound IF channel have not been produced for some years and therefore are not considered.

In all tests, it is assumed that the input signal consists of both the picture and sound signals, and that the ratio of the sound-to-picture carrier is unity, unless otherwise specified. The difference frequency between the carriers must be maintained accurately at 4.5 mc ±5 kc.

All measurements described are on the basis of an over-all test. However, particularly in making design rather than performance measurements, it is frequently advantageous to check the 4.5-mc intercarrier sound channel by breaking into the receiver at the video detector output with a 4.5-mc signal. Adequate isolation is required in this case to prevent loading and regenerative effects.

8.2 Sound Sensitivity

The sensitivity of the sound channel is measured under the same conditions as the nominal picture sensitivity (Section 4.2) and the peak picture sensitivity (Section 4.3). The corresponding sensitivities for the sound channels are termed the nominal sound sensitivity and the peak sound sensitivity, respectively.

8.3 Nominal Sound Sensitivity

8.3.1 Definition. This is the lowest input signal required to produce standard sound test output when the receiver is tuned to produce the nominal intermediate frequency.

8.3.2 Method of Measurement. The receiver under test is connected to the sound and picture signal generators through the standard 300-ohm dummy antenna (Section 1.7.3) and tuned as described in Section 1.10.5.2 to produce the nominal intermediate frequency. Unity ratio is maintained between sound and picture carriers. The sound signal generator is frequency modulated 30 per cent (7.5-kc deviation) at a 400-cps rate. The picture-signal generator is modulated with standard white-pattern modulation (Section 1.5.2), and the receiver controls are adjusted as in measuring the picture sensitivity (Section 4.2). The volume control is at maximum and the tone control is set for maximum 400-cps response. The signal generator outputs are adjusted to obtain standard sound test output (Section 1.9) across the dummy load. The output meter should be connected across the load through a 400-cps bandpass filter to reject the random noise output (Fig. 8.3.2).

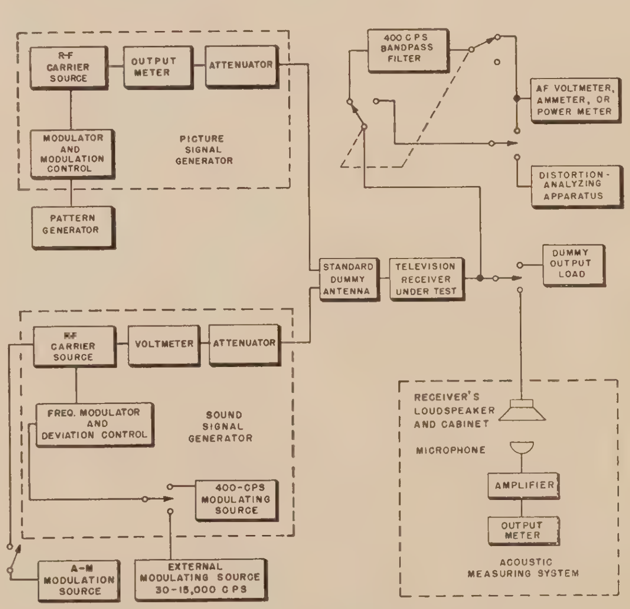
R-F CARRIER SOURCE
OUTPUT METER
ATTENUATOR
MODULATOR AND MODULATION CONTROL
PICTURE SIGNAL GENERATOR
PATTERN GENERATOR
400 CPS BANDPASS FILTER
AF VOLTMETER, AMMETER, OR POWER METER
DISTORTION-ANALYZING APPARATUS
STANDARD DUMMY ANTENNA
TELEVISION RECEIVER UNDER TEST
DUMMY OUTPUT LOAD
R-F CARRIER SOURCE
VOLTMETER
ATTENUATOR
FREQ. MODULATOR AND DEVIATION CONTROL
SOUND SIGNAL GENERATOR
400-CPS MODULATING SOURCE
A-M MODULATION SOURCE
EXTERNAL MODULATING SOURCE 30-15,000 CPS
RECEIVER'S LOUDSPEAKER AND CABINET
MICROPHONE
AMPLIFIER
OUTPUT METER
ACOUSTIC MEASURING SYSTEM

Fig. 8.3.2—Block diagram of equipment for testing the over-all performance of the sound section of a television receiver

8.4 Peak Sound Sensitivity

8.4.1 Definition. This is the lowest input signal required to produce standard sound test output when the receiver is tuned as in measuring peak picture sensitivity (Section 4.3).

8.4.2 Method of Measurement. The procedure is the same as Section 8.3.2 except for the receiver tuning.

8.5 Quieting Sensitivity

8.5.1 Definition. The quieting sensitivity is the lowest input signal required to reduce the noise output to a value which is 30 db below the output obtained when standard test modulation (Section 1.6) is applied to the sound carrier.

8.5.2 Method of Measurement. The procedure is similar to that for measuring nominal sound sensitivity (Section 8.3) except that the volume control is adjusted to maintain standard sound test output (Section 1.9) and the tone controls are adjusted to provide a flat over-all response (allowing for normal transmitter pre-emphasis). The standard sound test modulation is then switched on and off, while the input signal is reduced until a value is reached at which a 30-db difference in indicated output is noted between the modulated and unmodulated conditions. This value of input signal is the quieting sensitivity.

8.6 Signal-to-Noise Ratio

To supplement the quieting sensitivity (Section 8.5), it is desirable to measure the signal-to-noise ratio as a function of input signal. The picture and sound signal generators are connected to the receiver as described in Section 1.7. White-pattern modulation (Section 1.5.2) is used for the picture and 400-cps 30 per cent modulation for the sound. The receiver controls are adjusted for normal operation. At each input level the sound output is observed with the volume control set for standard output and the tone controls adjusted as in Section 8.5.2. A 400-cps band-pass filter should be used to reject noise (Fig. 8.3.2). The modulation is then switched off, the filter removed from the circuit, and the noise output measured. The signal-to-noise ratio is expressed in decibels and plotted as a function of the input signal (Fig. 8.6). Hum, deflection voltage pickup, and video interference should not be included in this noise measurement; these are separately evaluated (Section 10.4).

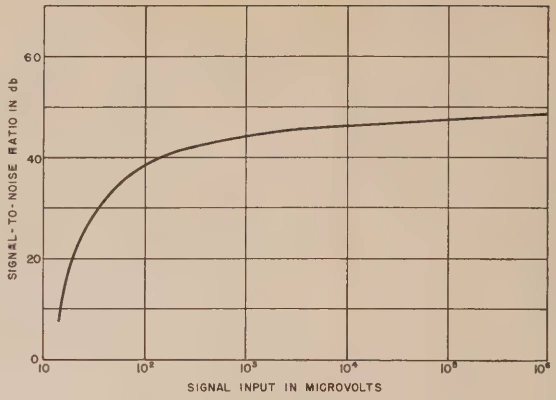

Fig. 8.6—Signal-to-noise ratio.

8.7 AGC Characteristic

Refer to Section 4.5.

8.8 Limiting Characteristic

8.8.1 Introduction. The limiting characteristic shows the variation in the sound output as the sound carrier amplitude is varied, the picture carrier amplitude being maintained constant. The degree of limiting affects the variation in sound output with receiver tuning. It also affects the suppression of amplitude modulation and interference (Section 9.2), although this suppression is accomplished by other than static limiting in many receivers.

8.8.2 Method of Measurement. The limiting characteristic is measured by connecting the picture and sound signal generators as in Section 1.7, using standard mean-signal input level. Standard gray-pattern modulation is used (Section 1.5.3). The sound carrier is 30 per cent modulated at 400 cps, and the volume control is set for standard output at the maximum point on the output characteristic. The sound carrier amplitude is varied below and above the nominal 1:1 sound-to-picture carrier ratio and the sound output is plotted against the sound-to-picture carrier ratio.

Chapter 9—Interference, Sound Section

9.1 Selectivity and Spurious Responses

The over-all selectivity curve (Section 5.2.1) provides a measure of the susceptibility of the sound channel to interference from adjacent-channel signals and other undesired signals. For example, the susceptibility to adjacent-channel picture carrier interference is usually determined by the selectivity for a signal 1.5 mc above the desired sound carrier frequency.

The test procedure used to check spurious responses in the picture channel is applicable to the sound channel as described in Section 5.2.4.

The sound IF circuits which are tuned to the 4.5-mc intercarrier frequency are sufficiently selective with conventional design so that measurement of their selectivity is not normally required.

9.2 Amplitude-Modulation Suppression Ratio

9.2.1 Introduction. The AM suppression ratio is a measure of the ability of the sound channel to reject undesirable amplitude modulation of the sound carrier. This amplitude modulation can occur, for example, as a result of cross-modulation of the sound carrier with the modulated picture carrier.

Two methods are described for measuring the suppression of amplitude modulation: 1) the meter method (Section 9.2.2) and 2) the oscilloscope method (Section 9.2.3). The meter method has the advantage of being more sensitive and providing a more quantitative measure of amplitude-modulation suppression for receivers which have a high degree of suppression. The oscilloscope method, although less sensitive, frequently provides useful design information not directly obtainable from the meter method.

9.2.2 Meter Method. The picture and sound signal generators are connected to the receiver as described in Section 1.7. Standard white-pattern modulation (Section 1.5.2) is used for the picture carrier. The receiver controls are adjusted for normal operation with the generators set at standard mean-signal input level.

The sound carrier is simultaneously frequency- and amplitude-modulated. The sound carrier is 30 per cent frequency-modulated at between 50 and 70 cps and 30 per cent amplitude-modulated at 400 cps. A 400-cps high-pass filter is used to measure the output resulting from the amplitude modulation. This choice of AM and FM frequencies has the advantages that harmonic distortion of the FM output and incidental undesired frequency modulation of either the picture or sound carriers at power-supply frequency are rejected by the high-pass filter.

The sound signal generator must have negligible incidental frequency modulation when it is amplitude-modulated. The picture signal generator must also satisfy this requirement. Unless the equipment is known to have negligible incidental frequency modulation, an external amplitude modulator, adequately isolated, should be used.

The output resulting from the 30 per cent frequency modulation is measured with the amplitude modulation removed. The 30 per cent amplitude modulation is then simultaneously applied to the sound carrier and the 400-cps high-pass filter is used to measure the output resulting from the amplitude modulation. The ratio of the two outputs, corrected for the filter attenuation, and expressed in decibels, is the AM suppression ratio.

The measurement is normally made on one channel for various input signal levels. Repetition of the measurement for higher percentages of amplitude modulation and at other amplitude-modulation frequencies provides useful data.

To eliminate the effect of noise, it is frequently desirable to carry out the measurement at mean-signal level with unity sound picture carrier ratio, and to repeat the measurement with the sound carrier amplitude as the parameter. Alternatively, the measurement can be made at the 4.5-mc intercarrier beat frequency (Section 8.1).

9.2.3 Oscilloscope Method. In the oscilloscope method, the procedure is similar to that for the meter method. However, the sound output is connected to the vertical plates of an oscilloscope, while the AF generator which frequency-modulates the sound carrier is connected to the horizontal plates so as to produce the display shown in Fig. 9.2.3. Correction for phase shift may be required to close the pattern.

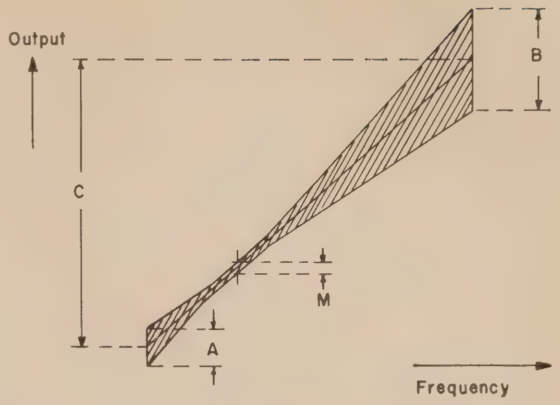

Fig. 9.2.3—Display of amplitude-modulation-suppression ratio on the oscilloscope.

The formulas shown below define an unbalanced suppression ratio, a balanced suppression ratio and a maximum suppression ratio:

$$\text{Unbalanced suppression ratio} = R_u = 2\left|\frac{C}{A-B}\right|$$

$$\text{Balanced suppression ratio} = R_b = 2\left|\frac{C}{A+B}\right|$$

$$\text{Maximum suppression ratio} = R_m = \left|\frac{C}{M}\right|.$$

The expressions for R_u and R_b are applicable only when the pattern is as shown in Fig. 9.2.3. When the crossover point is outside the displayed pattern, the expressions for R_u and R_b become:

$$R_u = 2\left|\frac{C}{A+B}\right|$$

$$R_b = 2\left|\frac{C}{A-B}\right|$$

The procedure described in connection with the meter method is applicable to the oscilloscope method.

Although 30 per cent frequency modulation is used in measuring these suppression ratios, as in the meter method, it is desirable to increase the frequency modulation to at least 100 per cent in order to view the complete discriminator characteristic.

Chapter 10—Fidelity, Sound Section

10.1 Electric and Acoustic Fidelity

This chapter describes methods for measuring the electric fidelity, including the amplitude-vs-frequency response, harmonic distortion, and power output of the audio signal delivered to the dummy load which replaces the speaker. The acoustic fidelity is measured by applying the same signal generator and receiver procedures, with the speaker in the completely assembled cabinet replacing the artificial load. Acoustic measuring procedures are described in other IRE standards.

10.2 *Amplitude-vs-Frequency Response*

10.2.1 Definition. The amplitude-vs-frequency response shows the manner in which the electrical output delivered to the dummy load reproduces the modulating audio signal. It takes into account all characteristics of the receiver except those of the loudspeaker.

10.2.2 Method of Measurement. The picture and sound signal generators are connected to the receiver which is adjusted for normal operation as in Section 1.10.5. Mean-signal input level and 30 per cent sound modulation are used. The receiver volume control is adjusted so that the point of maximum response in the audio frequency range gives standard sound test output. The output is observed while the modulation frequency is varied continuously from 30 to 15,000 cps.

If the receiver has one or more tone controls, the response is plotted for the adjustment which gives the maximum bass and treble compensation. The tests should be repeated for minimum and mean settings of the tone controls.

If the response changes substantially with the volume control setting, this test should be repeated at selected power levels.

Since no pre-emphasis is employed in the sound signal generator, the measured power output values should be corrected by adding the values corresponding to the standard receiver de-emphasis curve, which has the absolute values shown in Fig. 1.6.

The presence of overload at any point should be noted.

10.2.3 Presentation of Data. The results are plotted with the frequency as the abscissa on a logarithmic scale and the power output in decibels as the ordinate on a linear scale. The 400-cps output is taken as the 0-db reference level and the corresponding absolute power is noted on the graph.

10.3 *Harmonic Distortion*

10.3.1 General. The over-all harmonic distortion in the electrical output is measured for a wide variety of signal and operating conditions. From these measurements it is possible to determine the part of the receiver which is responsible for the distortion.

Nonlinear distortion in the signal generating and measuring equipment must be negligible.

10.3.2 Definition. The harmonic distortion is determined by the percentage of the rms value of the harmonics in the output when a pure sinusoidal modulating signal is used, the formula being

$$K = \frac{\sqrt{E_2^2 + E_3^2 + E_4^2 + \cdots}}{\sqrt{E_1^2 + E_2^2 + E_3^2 + E_4^2 + \cdots}} \times 100 \text{ per cent.}$$

E_1 is the fundamental-frequency voltage and E_2, E_3, E_4, etc. are the voltage values of the individual harmonics present across the dummy load.

Hum, deflection, and video components are not included in harmonic distortion.

A distortion analyzer will read the rms value of the total distortion, while a wave analyzer is required if the individual harmonics are of interest.

10.3.3 Method of Measurement. The picture and sound signal generators are connected to the receiver as described in Section 1.7. Standard gray-pattern modulation is used. Unless otherwise specified, standard mean-signal input level is used and the controls are adjusted for normal operation. If interference from either the power supply, video, or deflection system is encountered, suitable precautions are taken so that the harmonic distortion measurement is not affected. A wave analyzer may be used to measure the individual harmonics.

The distortion is measured with the following characteristics as the principal parameters:

10.3.3.1 Distortion vs power output. The modulation is fixed at 30 per cent, the modulation frequency at 400 cps, and the harmonic distortion is plotted as the output is varied by means of the volume control.

The *power output for 10 per cent harmonic distortion* and the *maximum power output* without regard to distortion are individually noted.

The *residual power output* is the output corresponding to minimum setting of the volume control.

10.3.3.2 Distortion vs percentage modulation. The modulation frequency is fixed at 400 cps and the output is maintained at standard test output by adjustment of the volume control (where possible). The harmonic distortion is plotted as the modulation is varied from 10 per cent to 200 per cent.

The procedure is repeated with the output held at a level 10 db below standard test output so that output-stage distortion is minimized.

10.3.3.3 Distortion vs modulation frequency. The modulation is fixed at 30 per cent and the output is maintained at standard test output. The modulation frequency is varied and the harmonic distortion is measured.

The preceding measurements are supplemented where necessary by measurements which show the effect of power output, tone control setting, input signal level, and sound-to-picture carrier ratio. In particular, the presence of distortion due to stray coupling at low volume should be noted.

10.4 *Power Supply (Hum), Deflection, and Video Interference*

10.4.1 Introduction. The tests in this section are designed to detect interference in the sound output which may arise from causes such as inadequate power supply filtering (hum), coupling to the deflection circuits, and coupling to the video circuits (buzz).

The nuisance value of this interference depends upon its waveform as well as its rms value and the acoustic frequency response of the receiver.

10.4.2 Method of Measurement. The picture and sound signal generators are connected to the receiver as described in Section 1.7. Except where otherwise specified, standard white-pattern picture modulation and 30 per cent 400-cps sound modulation are used, and the receiver controls are adjusted for normal operation. The sound output delivered to the dummy load is observed with both a meter and an oscilloscope.

10.4.2.1 Interference output—volume control at standard test output setting. The volume control is set at the position which produces standard test output and the sound modulation is switched off. The amplitude and waveform of the interference output is noted for the worst setting of the tone controls.

The receiver contrast control and the depth of picture modulation are increased and the conditions resulting in interference are noted.

10.4.2.2 Interference output—volume control at minimum setting. The volume control is set at minimum. The sound modulation is switched off and the interference output is noted.

10.4.2.3 Hum modulation. With the sound modulation on and standard test output, the waveform or spectrum of the sound output is observed to detect the presence of intermodulation, including power supply, hum, deflection, or video components.

10.4.3 Presentation of Data. The amplitude, waveform, and source of the interference should be specified and the conditions of measurement.

These interference measurements in particular should be supplemented by listening tests to evaluate qualitatively the interference under normal operation.

Chapter 11—Radiated and Conducted Emissions

11.1 General Considerations

Television receivers which cause interference to other receivers and services generally have been found to produce it in either of two ways: at higher frequencies by waves radiated from the chassis, transmission line and antenna; and at lower frequencies by waves conducted over the power line.

11.2 Radiated Interference

The method of measurement is given in IRE Standards 51 IRE 17. S1.[8] The results are stated in microvolts per meter at a distance of 100 feet, at each frequency.

11.3 Conducted Interference

The method of measurement is given in IRE Standards 54 IRE 17. S1,[9] in the supplement to these standards 58 IRE 27. S1,[10] and in IRE Standards 56 IRE 27. S1.[11] The results are stated in microvolts, at each measurement frequency, across the standard power-line impedance network.

Chapter 12—Miscellaneous

12.1 Receiver Input Impedance

12.1.1 Introduction. Although the magnitude and phase angle of the complex impedance at the input terminals of the receiver can be measured, it is usually of more interest to know either the voltage standing wave ratio, VSWR, produced in the transmission line, or the absolute value of the reflection coefficient, ρ, which are related as follows:

$$\text{VSWR} = \frac{1 + |\rho|}{1 - |\rho|}.$$

When the imput impedance varies across the channel, the VSWR for frequencies in the region of the picture carrier is of primary interest. The input impedance is often a function of signal level.

12.1.2 Definitions. The voltage standing wave ratio is the ratio of the maximum to the minimum voltage that appears at points along the transmission line. The reflection coefficient is the complex ratio of the voltage of the reflected wave to the voltage of the incident wave.

12.1.3 Method of Measurement. A long transmission line of the specified characteristic impedance is connected to the input terminals of the receiver, which is switched on and tuned to the appropriate channel. The AGC voltage applied to the first amplifier in the receiver should be stabilized at the value corresponding to a weak applied signal. A signal generator is connected to the other end of the transmission line. The generator applies an unmodulated radio-frequency signal of constant voltage (open-circuit) and variable frequency to this end of the transmission line. The strength of the signal at this end is measured with a detector. The combination of the signal generator and the detector must terminate the transmission line accurately with its characteristic impedance [see Fig. 12.1(a)]. The signal strength is plotted as a function of the input signal frequency, first with the receiver end of the transmission line short-circuited and secondly with the receiver end of the transmission line connected to the antenna input terminals of the receiver. From these two curves, the VSWR is derived, using the relation

$$\text{VSWR} = \frac{V_2 + V_1}{V_2 - V_1}.$$

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[8] "IRE Standards on Radio Receivers: Open Field Method of Measurement of Spurious Radiation from Frequency Modulation and Television Broadcast Receivers, 1951," Proc. IRE, vol. 39, pp. 803–806; July, 1951.

[9] "IRE Standards on Receivers: Methods of Measurement of Interference Output of Television Receivers in the Range of 300 to 10,000 kc, 1954," vol. 42, pp. 1363–1367; September, 1954.

[10] "Supplement to 'IRE Standards on Receivers: Methods of Measurement of Interference Output of Television Receivers in the Range of 300 to 10,000 kc, 1954,' " vol. 46, pp. 1418–1420; July, 1958.

[11] "IRE Standards on Methods of Measurement of the Conducted Interference Output of Broadcast and Television Receivers in the Range of 300 Kc to 25 Mc, 1956," vol. 44, pp. 1040–1043; August, 1956.

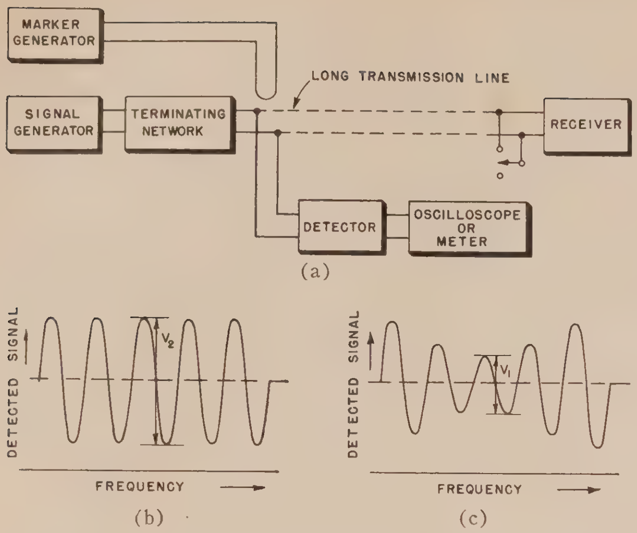

Fig. 12.1—(a) Circuit arrangement for measurement of voltage-standing-wave ratio. (b) Detected signal with receiver end of the transmission line short-circuited. (c) Detected signal with transmission line terminated with the receiver input terminals.

The transmission line must be long enough so that a sufficient number of undulations is recorded within a frequency range corresponding to the pass band of the receiver. The frequency separation between adjacent minima is

$$f = \frac{v}{2l},$$

where

v = velocity of propagation of the transmission line, and

l = length of the transmission line,

when the far end of the transmission line is short-circuited. The attenuation of the transmission line must be low enough so that the undulations are of sufficient amplitude when the far end of the transmission line is short-circuited.

By using a sweep signal generator the detected signal can be displayed on an oscilloscope. If the detector is not linear, a calibration of the indication is necessary. The applied signal should not be so large that the input portion of the receiver is overloaded. The tests should be repeated with the AGC voltage fixed at values corresponding to higher input levels.

12.1.4 Presentation of Data. The VSWR is stated for each channel and input level measured. When the VSWR varies across the channel, the stated value should be for frequencies in the region of the picture carrier.

12.2 Change in Band-Pass by Antenna Mismatch

12.2.1 Definition. The change in band-pass by antenna mismatch is defined as the change in selectivity produced by a 4-to-1 change in the dummy-antenna impedance from the matched value, when the transmission line between the dummy antenna and the receiver is varied in electrical length over a range of one-half wavelength, keeping the amplitude of the response at the picture carrier frequency constant. This measurement is designed to simulate results which are obtained with conventional antennas which cause mistuning and loading of the receiver input circuits.

12.2.2 Method of Measurement. The equipment is arranged to measure the selectivity as in Section 5.2.1, or a sweep oscillator and oscilloscope display may be used, with markers at the picture carrier frequency and at 3 mc higher. Provision is made to change the dummy-antenna impedance to either one-fourth or four times the standard value (300 ohms). The AGC voltage should be stabilized at the value corresponding to the signal level being used. Using the standard dummy antenna, the response at the picture carrier frequency is set to standard test output, and the response at other frequencies of interest measured. The standard dummy antenna is then replaced by the mismatched dummy antenna, and the signal input adjusted to give the same response at the picture carrier frequency. The response at the other frequencies is again measured. The transmission line between the dummy antenna and the receiver is replaced by one having an electrical length of one-eighth wavelength greater, and the process repeated. Several lengths of transmission line, up to one-half wavelength greater electrical length than the original, are substituted.

The tests should be repeated for applied signals of different levels.

12.2.3 Presentation of Data. The maximum change in response at each frequency of interest is given in decibels. The change in response at the frequency corresponding to 3-mc video modulation, and at the sound carrier frequency, should be included.

Correspondence

Operation of an Esaki Diode Microwave Amplifier*

A microwave amplifier using a germanium Esaki diode has been operated at 4.5 kmc with the following results:

Maximum stable gain ≃23 db;
Voltage gain—bandwidth product ≃2.75×10^8;
(23-db gain at a bandwidth of 20 mc)
Effective source noise temperature ≃1200°K;
(noise figure =7 db)
Saturation power output ≈1×10^{-6} watt.

The diode peak current was 1.1 ma and the peak-to-valley ratio was 2.5.

The amplifier is shown schematically in Fig. 1. It consists of a single port cavity A, containing the Esaki diode B, which is coupled via an iris to a short section of a waveguide beyond cutoff C, separating it from the main propagating waveguide D. The incident input signal and the reflected (and amplified) output signal are separated by a low-loss circulator.

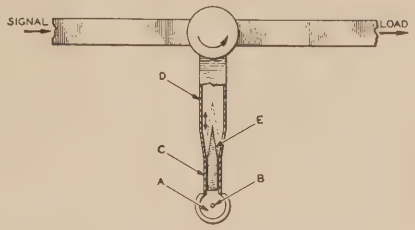

Fig. 1—A schematic view of the Esaki diode amplifier. (The symbols are explained in the text.)

As with all regenerative amplifiers, sufficient loading must be provided to prevent oscillation from taking place. This was achieved by a dielectric plug, E, which, when completely inserted into the cutoff section, enables the latter to propagate. The depth of insertion is thus used to vary the external coupling of the cavity.[1]

It can be shown that, for high gain, the voltage gain-bandwidth product is given by

$$\sqrt{G}\,\Delta f \approx \frac{1-\dfrac{Q_d}{Q_c}}{\pi RC}, \tag{1}$$

where Q_d/Q_c is the ratio of the power dissipated inside the cavity to that generated by the negative resistance of the diode. R and c are, respectively, the negative resistance and the capacitance of the diode. G is the power gain while Δf is the separation in cycles/second between the half-power points The constancy of $\sqrt{G}\Delta f$ was checked at $G=23$ db and $G=17$ db. Since Q_d/Q_c in our experiment was ~ 0.5, the measured result, $\sqrt{G}\Delta f=2.75\times10^8$, represents approximately one half of the asymptotic value attainable according to (1) in the limit of strong overcoupling, $Q_c \gg Q_d$.

The effective source noise temperature T_e[2] is given by the relation

$$T_e = \frac{(\sqrt{G}+1)^2}{G} \cdot \left[T_c\left(\frac{Q_{ex}}{Q_c}\right) + \frac{eI_0R}{2k}\left(\frac{Q_{ex}}{Q_d}\right)\right] \tag{2}$$

where

T_c is the cavity ambient temperature;

$$\frac{Q_{ex}}{Q_c} = \frac{\text{external “}Q\text{”}}{\text{unloaded “}Q\text{”}}$$

is the ratio of the power lost in the cavity to that delivered to the external load;

Q_{ex}/Q_d is the ratio of the power generated by the diode to that supplied to the load;

I_0 is the dc bias current;

e is the electronic charge;

k is Boltzmann constant; and

$-R$ is the negative resistance of the diode.

The measured noise temperature of 1200°K was approximately twice as high as that expected from (2) in the limit of strong coupling where $Q_{ex} \ll Q_c$. This difference is due to the operation of the cavity near the condition of critical coupling. An increase in coupling was prevented by the amount of parasitic losses inside the cavity, which placed a limit on the maximum loading at which high gain could be obtained. Substantially lower noise temperatures are to be expected from diodes with better peak-to-valley current ratios (where lower values of I_0R can be attained), and from diodes with smaller series resistance. There is also the possibility of intrinsically lower I_0R products with other semiconductors.

The authors wish to express their gratitude to E. Dickten who fabricated and mounted the diode used in the experiment.

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* Received by the IRE, February 16, 1960.

[1] This scheme was first used by J. P. Gordon in a paramagnetic resonance experiment.

[2] T_e is related to the noise figure F by the relation

$$F = 1 + \frac{T_e}{290}.$$

Voltage Tuning in Tunnel Diode Oscillators*

During some recent experimental work on microwave tunnel diode oscillators, voltage tuning ranges of up to 12 per cent have been obtained by varying the operating bias of the oscillator. Power output was approximately −30 dbm.

Fig. 1 shows a curve of frequency vs voltage obtained with an oscillator using an Esaki diode, manufactured by Sony Corporation, Japan. The diode was mounted at one end of a low impedance coaxial line, as shown in Fig. 2, and the other end of the line was terminated in a matched load, across which the operating voltage was applied.

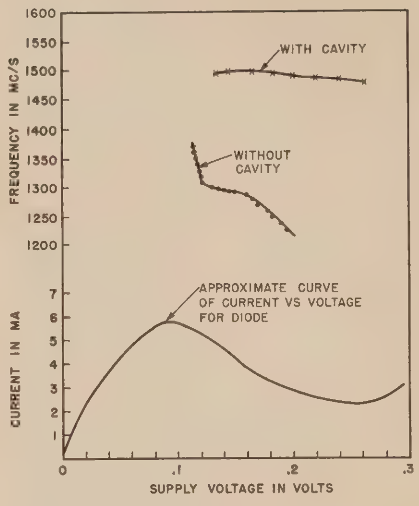

Fig. 1—Voltage tuning curves for tunnel diode oscillator.

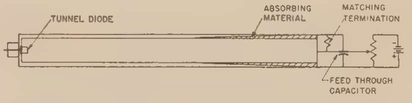

Fig. 2—Tunnel diode oscillator (output was taken from a probe at the diode end).

The dependence of frequency on the operating potential in a voltage-controlled negative resistance oscillator is a well-known phenomenon. The mechanism is particularly clearly explained by Edson.[1] As the diode has a nominal maximum negative resistance of 25 ohms, and the impedance of the coaxial line is 20 ohms, there is quite a wide band near the resonant frequency of the diode package where the diode can oscillate.

By varying the operating voltage, the effective negative resistance of the diode at which the oscillation will reach a steady state may be varied, and thus the frequency will change. The relative amplitude and phase of the harmonics generated will also vary with supply voltage, and, as shown by Edson, this also affects the oscillation frequency. The nonlinearity of frequency vs voltage is thought to be due to resonances at the harmonic frequencies.

By adding a quarter wave re-entrant cavity in the center conductor of the coaxial line, the impedance at the oscillating frequency can be raised, resulting in more power output (approximately −15 dbm) but a voltage tuning range of only about 20 mc at 1500 mc or 1.3 per cent. Both oscillators could be tuned mechanically over a 30 per cent bandwidth with little change in output.

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* Received by the IRE, February 29, 1960.

[1] W. A. Edson, "Vacuum Tube Oscillators," John Wiley and Sons, Inc., New York, N. Y.; 1953.

A Technique for Cascading Tunnel-Diode Amplifiers*

The tunnel diode can often be used as the active element in a conventional amplifier stage. It is at times desirable to cascade such amplifiers. Since the tunnel diode is a two-terminal device it does not supply the isolation of either the vacuum tube or the transistor. Thus, special techniques must be used when cascading tunnel-diode amplifiers. Such a technique is presented here. For convenience, voltage amplification will be discussed although a similar discussion could be applied to current amplification or power amplification.

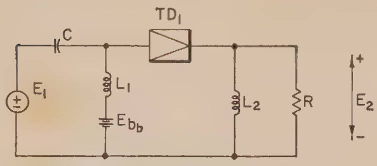

Fig. 1—A simple tunnel-diode amplifier.

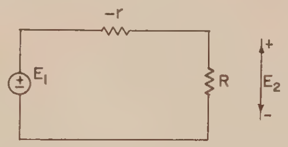

Fig. 2—The equivalent circuit for the simple tunnel-diode amplifier of Fig. 1.

Let us consider the simple tunnel-diode amplifier shown in Fig. 1. We shall assume that L_1 and L_2 are such that they act as open circuits at all frequencies of interest, while C is such that it acts as a short circuit at all frequencies of interest. The elements L_1, L_2, and C are used to supply direct bias. The equivalent circuit for the tunnel diode can be represented simply by a negative resistance over a wide range of frequencies. This will be done here. The equivalent circuit for this amplifier is shown in Fig. 2. The voltage gain of this circuit is given by

$$K = \frac{E_2}{E_1} = \frac{R}{R - r}\,. \qquad (1)$$

Note that K can be made as large as desired by choosing $-r$ so that $R-r$ is sufficiently small. However, stability requirements usually limit the maximum value of K. If the maximum allowable gain per stage is less than the required over-all gain, then several amplifier stages must be cascaded. As it stands, this amplifier does not lend itself well to cascading. However, the addition of a second tunnel diode, which does not change the voltage gain, results in an amplifier that can be easily cascaded. Such an amplifier and its equivalent circuit are shown in Figs. 3(a) and 3(b), respectively. Note that the negative resistance of TD_1 may be different from that of TD_2. It is assumed that there are tunnel diodes with the required negative resistances. If this is not the case, then the required negative resistance can be obtained by combining a tunnel diode with a positive resistance. The voltage gain of this circuit is the same as that of Fig. 1 and is given by (1). However, the input resistance of the circuit of Fig. 1 is $R-r$, while the input resistance of the circuit of Fig. 2 is given by

$$R_{\text{in}} = \frac{-r_1(R - r)}{R - r - r_1}\,. \qquad (2)$$

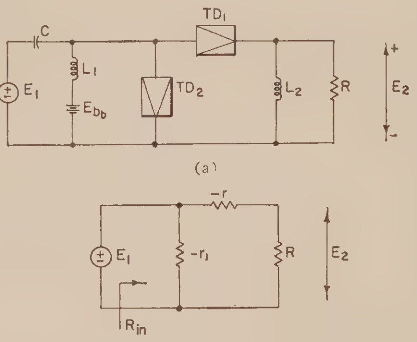

Fig. 3—(a) A tunnel-diode amplifier that can be cascaded; (b) its equivalent circuit.

Now let us choose $-r_1$ so that $R_{\text{in}} = R$. Then solving (2) for $-r_1$, we obtain

$$-r_1 = \frac{R(R - r)}{-r}\,. \qquad (3)$$

The input resistance of this circuit is now equal to the load resistance, thus this circuit may be used as the "load resistance" of a similar circuit. When several of such stages are cascaded the voltage gain of each will be $K = R/(R-r)$. The over-all gain will, of course, be the product of the individual stage gains. For instance, a typical circuit is shown in Fig. 4(a). The over-all voltage gain of this circuit is K_1K^3, where $K_1 = R/(2R-r)$ is the gain of the first stage. Note that it has been assumed that the internal resistance of the signal source is not zero but is equal to the load resistor R. The equivalent circuit for this amplifier is shown in Fig. 4(b). Pertinent voltages and resistances are indicated in this equivalent circuit. The resistances are "viewed" in the direction shown by the arrow.

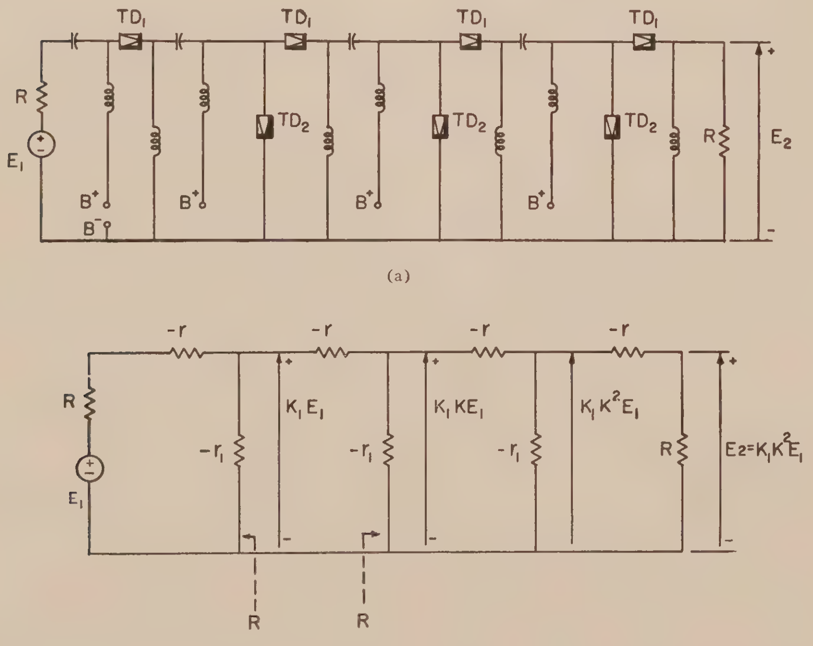

Fig. 4—(a) A typical cascaded tunnel-diode amplifier; (b) its equivalent circuit.

The previous discussion considered the cascading of amplifier stages. Actually, the circuit of Fig. 4 may be viewed as a transmission line connecting the input generator to the output load. In this case, the transmission line is made up of negative resistance elements and, hence, produces a gain rather than a loss. Note that with some minor modification this "transmission line" can start and end with shunt rather than series elements.

If impedances are placed in series with the series tunnel diodes (TD_1) and impedances are placed in shunt with the shunt tunnel diodes (TD_2), then the gain of the amplifier can be made frequency dependent. This must be done with care to insure that the amplifier will be stable.

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* Received by the IRE, February 15, 1960.

Negative *L* and *C* in Solid-State Masers*

When a material exhibiting quantum-mechanical resonance absorption is caused to be emissive by producing an inverted population distribution—which is necessary for maser operation—the impedance behavior of the material changes in two ways: not only does the resistive component become negative to provide gain, but the dependence of the reactive component on frequency reverses sign. This second property can be used to obtain gain and bandwidth performance that exceeds the limitations imposed by conventional network analysis. For amplifier design calculations, it is convenient to represent this fact by an equivalent circuit. For example, the permeability of a crystal in the neighborhood of a sharp electron paramagnetic resonance (for a Lorentz-shaped line) is of the form

$$\mu = \mu_0\left(1 - \frac{j\chi_{\max}''}{1 + jT_2\Delta\omega}\right) \tag{1}$$

where $\chi_{\max}''$ is the peak value of the absorptive component of complex susceptibility, and T_2 is the reciprocal linewidth. This relation may be represented by the equivalent circuit shown in Fig. 1 with $G=1/(\mu_0\chi_{\max}''\omega_0)$, and $jB=(jT_2\Delta\omega)/(\mu_0\chi_{\max}''\omega_0)$. When the population is inverted, the permeability becomes

$$\mu = \mu_0\left(1 + \frac{j\chi_{\max}''}{1 + jT_2\Delta\omega}\right),$$

for which the corresponding circuit becomes that shown in Fig. 2, in which all symbols are taken as positive. For a Gaussian-shaped line, the expressions are an approximation that is only valid in the center of the line, but the general conclusions are true.

This result is obtained by solving the equation of motion for the system in question,[1] and it can be readily observed experimentally. When the crystal is incorporated in a cavity resonator, an appropriate circuit suggested is that shown in Fig. 3. When the negative terms in this circuit are large compared with the positive terms (a situation that represents a strong paramagnetic resonance and a large filling factor), the circuit shown in Fig. 4 is suggested. The normal C'' and L'' are used to compensate for the negative L and C of the electron-spin resonance, to achieve increased bandwidth. The circuit of Fig. 4 represents two cascaded cavities with an inverted paramagnetic crystal in the second. In order to achieve significant improvement, L' must be small. The criterion suggested by stored-energy implications is

$$LG \leq \frac{C}{G} \tag{2}$$

and this has been verified by direct calcuiation.

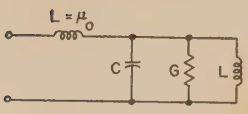

Fig. 1.

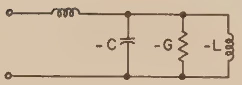

Fig. 2.

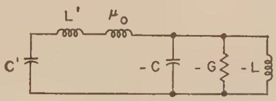

Fig. 3.

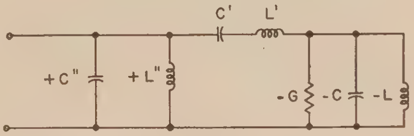

Fig. 4.

If a filling factor of 1 is obtained in the active cavity, (2) reduces to

$$\chi_{\max}'' \geq \frac{1}{\omega_0 T_2}, \quad \text{or} \quad \chi_{\max}'' \geq \frac{\Delta\omega_0}{\omega_0}, \tag{3}$$

where $\Delta\omega_0$ is the full width of the paramagnetic-resonance line. This condition is just about met for "pink" ruby at 9 kmc and at 4.2°K, for which, under typical experimental conditions, $\chi''\approx 0.01$, and $\Delta\omega_0/\omega_0 \approx 0.005$. Cavity losses, which are usually small under these conditions, were ignored in our analysis. A maser in which these phenomena are utilized has been constructed by Goodwin and Moss.[2]

The gain-bandwidth theory of Fano[3] can be extended to the negative *L* and *C* situation. In the high-gain limit, with a single maser crystal, it gives

$$\frac{1}{\pi}\int \ln \mathcal{G}^{1/2} d\omega = \Delta\omega_0 \cdot\left[\left(1 + \frac{3\chi_{\max}''\omega_0}{\Delta\omega_0}\right)^{1/3} - 1\right] \tag{4}$$

where the integral is over the amplifier bandwidth, and $\mathcal{G}^{1/2}$ is the voltage gain of the cavity maser as a function of frequency.

Increasing the spin concentration augments the effect by increasing χ'', as long as the linewidth $\Delta\omega_0$ does not increase also. Raising the operating frequency augments the effect for a given sample by increasing both χ'' and $\omega_0/\Delta\omega_0$. Lowering the temperature, of course, also helps.

The presence of the negative *L* and *C* terms does not materially change the performance of a typical traveling-wave maser because the circuit is too broad-band to introduce sufficient compensating reactance.

Incidentally, these negative *L* and *C* properties do not appear in parametric amplifiers. The broad-banding procedures discussed by Seidel and Herrmann,[4] for example, are of a more conventional type.

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* Received by the IRE, March 2, 1960. This work was supported in part by the U. S. Army (Signal Corps), the U. S. Air Force (Office of Scientific Research, Air Research and Development Command), and the U. S. Navy (Office of Naval Research).

[1] F. Bloch, "Nuclear induction," *Phys. Rev.*, vol. 70, pp. 460–474 (see sec. III); October 1 and 15, 1946; R. Karplus and J. Schwinger, "Saturation in microwave spectroscopy," *Phys. Rev.*, vol. 73, pp. 1020–1026 (see eq. 23); May 1, 1948.

[2] F. E. Goodwin and G. E. Moss, Hughes Aircraft Co., Research Labs., Culver City, Calif., private communication; November 12, 1959.

[3] R. M. Fano, "Theoretical limitations on the broadband matching of arbitrary impedances," *J. Franklin Inst.*, vol. 249, pp. 57–84; January, 1950; vol. 249, pp. 139–154; February, 1950.

[4] H. Seidel and G. F. Herrmann, "Circuit aspects of parametric amplifiers," 1959 IRE WESCON CONVENTION RECORD, Part 2, pp. 83–91.

Parametric Oscillatory and Rotary Motion*

The semiconductor parametric amplifier belongs to a more general class of devices, in which one or more parameters in the underlying integro-differential equation are periodic time functions. In principle, the reactance variation may equally well be accomplished by ferromagnetic means, so that the inductance becomes a periodic function. The conditions for oscillations are

$$L\frac{di}{dt} + i\frac{dL}{dt} + Ri + \frac{1}{C}\int i\,dt = 0, \tag{1}$$

$$C\frac{dv}{dt} + v\frac{dC}{dt} + Gv + \frac{1}{L}\int v\,dt = 0. \tag{2}$$

Here (2) is the better-known equation, pertaining to a variable-capacitance amplifier with $\beta A = 1$. The second term identifies the opportunity of amplification, offered with C varied at twice signal frequency. The capacitance variation frequency is the pump frequency, at which the capacitance is reduced on every half-cycle of the signal voltage wave, thus giving off energy to the rest of the system. This is the way the stimulance is injected, which in an amplifier almost, but not quite, takes care of the dissipation.

The writer has undertaken to investigate parametric devices with mechanical rather than electrical input signal.[1] Variable inductance devices at low frequency proved to offer the easiest approach, and several mechanical oscillators with equal pump and signal frequencies were successfully constructed. Thus, "the world's simplest servosystem" emerged, with the model adjusted for $\beta A < 1$. With the aid of the second term in (1), $i\,dL/dt$, a small mechanical displacement x was turned into a larger mechanical one, associated with much more power, and it is only logical to expect that a similar servosystem can be designed in accordance with (2). Thus a narrow-frequency-range oscillating reed, telephone, or loudspeaker design may be based on either equation, not to mention other devices of this general nature with or without supporting active elements, such as switching transistors.

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* Received by the IRE, March 1, 1960.

[1] H. P. Knauss and P. R. Zilsel, "Magnetically maintained pendulum," *Amer. J. Phys.*, vol. 19, pp. 318–320; May, 1951.

With the aid of a Mathieu-Hill type of equation solution, it can be shown that the term $i\,dL/dt$ yields a double-valued force function, the explanation for the easily demonstrated fact that sustained oscillations are obtained. To show that nonlinearity is not essential, an additional small-signal model was built without iron, and proved to oscillate. Since in the solution of the equation, the double-valued force function is independent of the sign of the displacement x, the association of the stimulance part of the force function with $-x$ is by no means unique; it could just as well be $+x$. To prove this theoretical point, predicting rotational motion, the "electronics motor" in Fig. 1 was constructed, and true enough it rotated. The favored speed of the model is about 200 rpm. The effect can be enhanced if a switching transistor amplifier of time constant T and with $Z_i \gg Z_\sigma$ is attached, for example, as indicated by the dotted lines. The transistor amplifier is not essential to the operation, nor is the capacitor C_1. This capacitor was introduced because it made the circuit approach resonance conditions, and thus accept a heavier current. It yields the frequency $1/2\pi\sqrt{L_1C_1}$, or which is lower than the lines frequency. Thus the slope $di/d\omega$ is negative, so that the stimulance part of the force function pertaining to $i\,dL/dt$ is aided by the force function due to $di/d\omega$, in which $\omega = 2\pi f$, with the particular value $f = 60$ designating lines frequency.

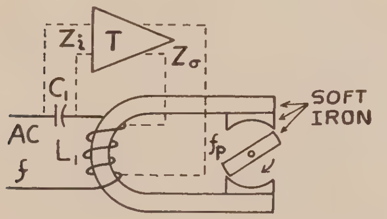

Fig. 1—Principle of the parametric motor. The rotor spins around in either direction, although there are no contacts, no rotor winding, no magnets, no rotational field, and no synchronous speed.

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A Transverse-Field Traveling-Wave Tube*

Recently there has been an urgent interest in traveling-wave parametric amplifiers which utilize an electron beam as the reactive element. One such amplifier which has achieved very-low-noise performance has been described by Adler *et al.*[1] The amplifier uses the fast electron cyclotron wave as the signal and idler modes and a traveling high-frequency electric quadrupole field as the pump mode. In the Adler Tube the pump frequency is set equal to twice the cyclotron frequency of the electrons and the phase velocity of the pump wave is infinite.

There is also a related class of beam-type parametric amplifiers in which the pump mode is at an arbitrarily low frequency including dc and the pump phase velocity is finite including zero. The idler mode is a slow cyclotron wave. These amplifiers are not characterized by extremely low-noise performance, but have other interesting properties as has been shown by Gordon *et al.*[2] It is the purpose of this paper to present preliminary experimental results on an amplifier using a static spatially-varying electric quadrupole field to achieve amplification of the fast cyclotron wave.

The interaction in the static quadrupole field can be understood by reference to Fig. 1 in which an electron in the phase appropriate to energy gain is shown. The drifting electron gains rotational energy as it loses drift energy; the quadrupole fields merely serving to deflect the electron. No energy is transferred from the quadrupole fields to the beam. It can be seen, also, that the synchronism condition requires that $2\omega_c = 2\pi v/L$, ω_c being the cyclotron frequency, v the drift velocity and L the periodic spacing of the quadrupole fields. Thus, the drifting electrons experience an apparent pump field of frequency $2\omega_c$.

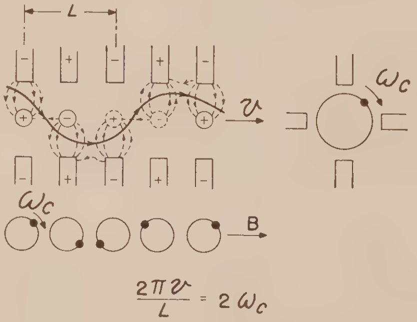

Fig. 1—The energy-gain mechanism.

As in the Adler device, an exponential growth of the orbit occurs which, coupled with a phase focusing induced by the quadrupole fields, leads to a net increase in the kinetic power of the fast cyclotron wave. Since no power is supplied by the pump fields and the drift velocity of the beam is decreased, it follows that the idler wave is a slow wave. Hence the zero pump frequency amplifier also may be compared to the conventional traveling-wave tube in which the corresponding "fast" wave is the electromagnetic wave carried by the slow-wave circuit while the "idler" wave is the slow space-charge wave.

The gain in the quadrupole fields is given by

$$G = 20 \log \cosh gV_q \text{ (db)} \qquad (1)$$

in which V_q is the dc voltage applied to the quadrupole plates and g is a geometrical factor proportional to the number of quadrupole sections. Fig. 2 shows the observed gain minus the insertion loss as a function of the quadrupole voltage with the beam at the synchronous voltage. The solid line is the curve predicted by (1) in which the value of the constant g has been adjusted. The value of the constant is 30 per cent higher than the value calculated from knowledge of the quadrupole geometry. The experimental points depart considerably from the predicted curve for gains above 8 db. At this point, interception on the quadrupole begins. This results from a defect in the electron gun which introduces up to twenty volts of rotational energy onto the beam and is not inherent in the device. The deficit in gain is a result of the interception and the departure from the synchronous condition resulting from the decrease in beam voltage of those electrons with large rotational energy. The beam voltage and current are 800 volts and 2 ma, respectively. The quadrupole structure has a periodicity of 0.25 cm with an inner diameter of 0.20 cm and has 10 periods. The couplers are ridged waveguide cavities with a center-band frequency of 3.25 kmc and a bandwidth of 2 per cent.

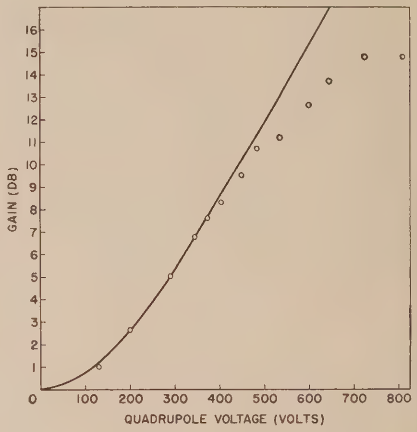

Fig. 2—Gain as a function of quadrupole.

A major advantage of the device is the fact that after the fast-wave energy is stripped from the beam in the output coupler, the remaining excitation on the beam is the slow idler wave. Thus, the spent electrons are monoenergetic and can be collected at close-to-cathode potential. As a result, the efficiency of the device can be very high.

No noise measurements have been made as yet, and although the device is not expected to have the extreme low-noise performance of the high-frequency-pumped amplifier, there is every reason to believe that it will compete with the more conventional traveling wave tubes in this respect.

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* Received by the IRE, March 7, 1960.

[1] R. Adler, G. Hrbek, and G. Wade, "The quadrupole amplifier, a low-noise parametric device," Proc. IRE, vol. 47, pp. 1713–1723; October, 1959.

[2] E. I. Gordon, S. J. Buchsbaum, and J. Feinstein, "A Transverse Field Amplifier Employing Cyclotron Resonance Interaction," paper presented at the Seventeenth Conference on Electron Tube Research, Mexico City, Mex.; June, 1959.

WWV and WWVH Standard Frequency and Time Transmissions*

The frequencies of the National Bureau of Standards radio stations WWV and WWVH are kept in agreement with respect to each other and have been maintained as constant as possible with respect to an improved United States Frequency Standard (USFS) since December 1, 1957.

The nominal broadcast frequencies should, for the purpose of highly accurate scientific measurements, or of establishing high uniformity among frequencies, or for removing unavoidable variations in the broadcast frequencies, be corrected to the value of the USFS, as indicated in the table below.

WWV FREQUENCY WITH RESPECT TO U. S. FREQUENCY STANDARD

1960 March 1600 UT	Parts in 10^{10}‡
1	−146
2	−146
3	−146
4	−146
5	−146
6	−145
7	−145
8	−145
9	−145
10	−145
11	−145
12	−144
13	−144
14	−144
15	−144
16	−144
17	−144
18	−145
19	−144
20	−144
21	−144
22	−144
23	−144
24	−144
25	−144
26§	−144
27	−147
28	−147
29	−147
30	−146
31	−146

‡ A minus sign indicates that the broadcast frequency was low.

§ On March 26 the frequency was decreased 3×10^{-10}.

The characteristics of the USFS, and its relation to time scales such as ET and UT2, have been described in a previous issue,[1] to which the reader is referred for a complete discussion.

The WWV and WWVH time signals are also kept in agreement with each other. Also they are locked to the nominal frequency of the transmissions and consequently may depart continuously from UT2. Corrections are determined and published by the U. S. Naval Observatory. The broadcast signals are maintained in close agreement with UT2 by properly offsetting the broadcast frequency from the USFS at the beginning of each year when necessary. This new system was commenced on January 1, 1960. The last time adjustment was a retardation adjustment of 0.02 s on December 16, 1959.

NATIONAL BUREAU OF STANDARDS
Boulder, Colo.

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* Received by the IRE, April 25, 1960.

[1] "United States National Standards of Time and Frequency," PROC. IRE, vol. 48, pp. 105–106; January, 1960.

Correction to "On the Regenerative Pulse Generator"*

Viktor Met, author of the above Correspondence, which appeared on pages 363–364 of the March, 1960, issue of PROCEEDINGS, has advised *the Editor* that the drawings of Figs. 2 and 3 were preliminaries, and should have been replaced with ones submitted at a later date. The revised figures are reproduced herewith.

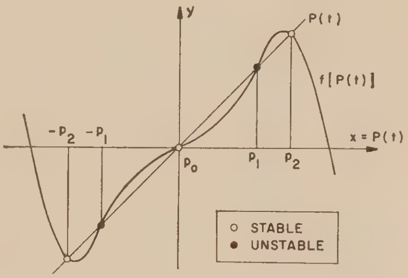

Fig. 2—Graphical solution of the nonlinear difference equation for a fifth-order nonlinearity.

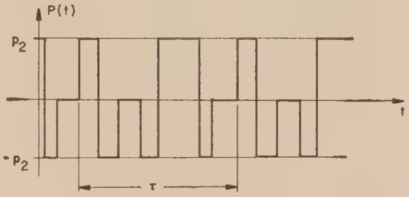

Fig. 3—Step-function, representing the general steady state solution.

* Received by the IRE, March 17, 1960.

Anomalous Reverse Current in Varactor Diodes*

While working on parametric amplifiers and harmonic generators using Varactor diodes, an interesting phenomenon was noticed concerning the direction of average diode current flow when a high-frequency pump source was applied. An appreciable reverse current was measured for dc bias voltages very much closer to forward conduction than to reverse breakdown. Measurements show that the instantaneous diode voltage is not even required to reach the dc breakdown value, and that this abnormal breakdown occurs only when the voltage during the positive-going half cycle is sufficiently large to swing into the forward conduction region. A plausible explanation of this phenomenon is that the large number of minority carriers injected during the forward half cycle are multiplied through collision ionization on the reverse half cycle, yielding a net negative current.[1] This occurs only at high frequencies because the voltage can swing negative before an appreciable number of injected carriers are lost through recombination or diffusion to the junction.

At X band, the effect is quite pronounced with a Bell Laboratories type Si 43 Varactor whose reverse characteristic is "hard" (less than 1-μa reverse current flows until breakdown occurs at −10.5 volts). An applied X band signal causes a reverse current of 20 μa at only −0.5 volt bias, although the diode characteristic is such that forward current of several microamperes occurs at +0.6 volt. For a slightly more positive value of bias, the current passes through zero and becomes positive. The dc bias at which the transition from forward to reverse current occurs was plotted as a function of frequency (Fig. 1). Since the ac drive varied over the frequency range, this curve should be regarded only as illustrating a trend. The anomalous effect is seen to be most pronounced for the highest frequencies and disappears below about 60 mc for the above diode. This frequency region agrees with the minority carrier lifetime of 0.05 μsec[2] for these diodes. Since the effect was small or negligible below several hundred megacycles, a direct observation of diode waveforms could not be made.

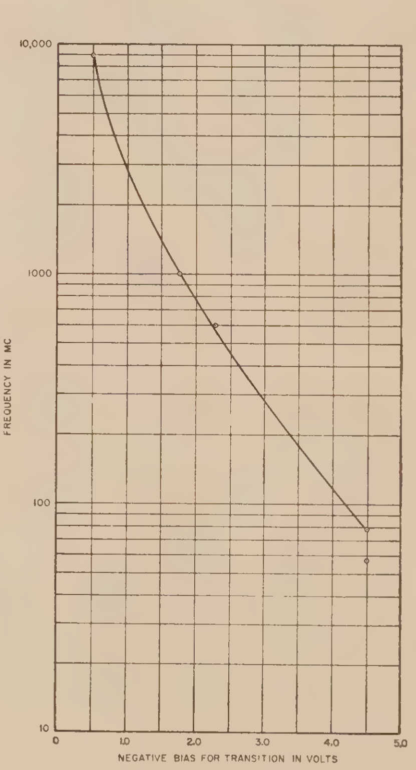

Fig. 1—Trend of effect vs frequency.

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* Received by the IRE, October 26, 1959. This work was supported under Air Force Contract AF30(602)-1854.

[1] Suggested by A. Uhlir, Jr., in a conversation held at Airborne Instruments Lab.

[2] "Crystal Rectifiers," Bell Telephone Labs., Ninth Interim Tech. Rep., Signal Corps Contract DA-36-039-sc-5589; October 15, 1956.

There are at least two explanations which may describe the above phenomena. One explanation requires that the ac signal be large enough to swing into both forward conduction and dc breakdown. Rectification about the forward characteristic should be poor because of minority carrier storage, and thus breakdown current should counterbalance the forward current at bias levels closer to forward conduction. This effect would be aided by the asymmetry of the waveform of voltage across the diode, which is peaked in the negative direction because of the shape of the C-V curve.

The second explanation is that the voltage does not reach the dc breakdown value, but at high frequencies some new mechanism occurs causing reverse current to flow at a voltage less than the normal dc breakdown voltage. To determine which explanation is correct, we have measured the voltage across the diode under conditions when the anomalous behavior was observed. This was done by two methods. The first method involved determining the amplitude of the various frequency components of the voltage across the diode by the use of a slotted line and reconstructing the waveform under the most pessimistic assumptions about phase. If the relative phases were such that all the peaks added in the negative direction, the maximum reverse voltage would only be 6.6 volts. This is considerably less than the value of 10.5 volts at which dc breakdown occurs.

At this point, we must mention the difference between the voltage we measure at the diode terminals and that which exists at the junction. The diode lead inductance is resonant with the junction capacitance from 3 to 4 kmc depending on the bias. The fundamental frequency was made low enough (470 mc) so that even at the third harmonic the parasitic elements introduce a negligible discrepancy.

For a second independent measurement to determine whether the diode voltage reaches dc breakdown, a high-frequency peak reading voltmeter (HP410B) was mounted in 50-ohm line directly in front of the diode and its coaxial mount. The meter response was flat to the fourth harmonic of the 185-mc signal used here. By reversing the diode and bias polarities with respect to the meter, both forward and reverse peaks were measured. They were +1.4 volts and −7.3 volts respectively. Again we see that the reverse peak does not reach the breakdown level.

Additional enlightenment as to the nature of the reverse conduction process results from a plot of average diode current vs bias for a fixed value of ac drive. (See Fig. 2.) The curve shown is for 370 mc. Similar results were found at other frequencies. The current is seen to be continuous through zero, indicating both forward and reverse current even at small bias levels. After switching from negative to positive it returns to zero for a range of bias values midway between the forward and reverse portions of the dc characteristic. This indicates that the voltage swing is too small to enter either conduction region when biased midway. Therefore, the negative current at small bias levels is not due to a large signal entering dc breakdown, but seems to depend upon forward current being drawn during part of the cycle. A further increase in bias results in breakdown current at −5.8 volts, indicating an ac amplitude of 4.7 volts. When this is added to the bias (2.8v) for the first crossover through zero, negative current is seen to be generated when the instantaneous voltage reaches −7.5 volts.

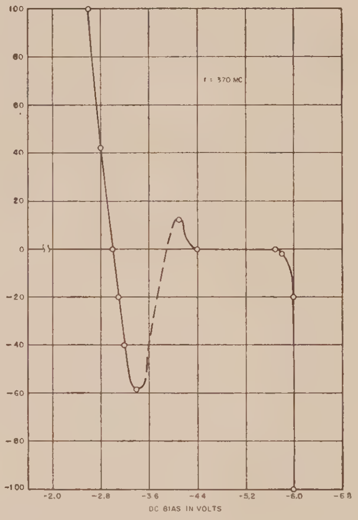

Fig. 2—Average diode current vs dc bias with ac drive (Si-43 No. 33).

The dashed portion of the curve denotes an unstable region, the operating point flipping from one extreme to the other. When biased in this region, a relaxation oscillation existed between these points at about 1 cps.

It should be noted that the circuits used have no structures tuned near the operating frequency, so that the variation of current with bias is not due to resonance effects involving the diode capacitance. The bias lead was suitably bypassed to ac.

Following the high-frequency experiments with the BTL Varactor diodes, the phenomenon was reproduced at low frequencies (15 mc) with a Hoffman 1N138 diode for which the lifetime was measured as about 1 μsec. The ratio of lifetime to RF period is seen to be of the same order of magnitude as in the high-frequency experiment. In addition, the breakdown mechanism is known to be of the avalanche type since this diode also exhibits the random pulse phenomenon described by McKay.[3] An oscilloscope verifies that the voltage is not required to reach dc breakdown, although the difference is not as great as in the high frequency case. A curve of average current vs diode bias similar to that of Fig. 2 was obtained, where the crossover through zero occurs at about −9 volts bias and the dc breakdown voltage is −27 volts.

It seems reasonable to conclude then that at RF periods which are short compared with the minority carrier lifetime, the carriers injected during the forward half cycle are multiplied through collision ionization on the reverse half cycle, resulting in a net reverse current. From the three high-frequency experiments presented, the maximum reverse voltage for anomalous current is about 7 volts. McKay has plotted the multiplication factor M vs V/V_b for a linearly graded silicon junction diode, where V_b is the breakdown voltage. For $V_b=10.5$, $V/V_b=0.7$, and the multiplication factor is about 2. Although this is not too much multiplication, the injected carriers represent a large increase in minority carrier density over the steady state level (of the order of 10^6). As a result, even a multiplication of two may yield considerable reverse current.

Conclusions have not yet been reached concerning the magnitude of the effects of this phenomenon on parametric amplifiers and harmonic generators, but it would seem to limit the voltage swing short of forward conduction under the penalty of an additional loss mechanism and some additional noise (even though the net dc current were zero, noise generated on the forward and reverse half cycles would degrade the noise figure of an amplifier). Operation in the nonconductive region between breakdown and forward conduction would avoid this effect, but considerable nonlinearity is probably lost by not driving into the forward region.

The author wishes to thank J. C. Greene, Dr. B. Salzberg and E. W. Sard for helpful discussions and suggestions.

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[3] K. G. McKay, "Avalanche breakdown in silicon," *Phys. Rev.*, vol. 94, pp. 877–884; May, 1954.

Relativity and the Scientific Method*

The recent Proceedings article by J. R. Pierce[1] has triggered considerable adverse comment[2] on Einstein's Theory of Relativity. In the maze of detail which was discussed, one very important principle was all but forgotten, *i.e.*, the operation of the scientific method.

The objective of physical science is to provide a theoretical basis for interpretation of the observed behavior of nature. Observations are thus the final and conclusive arbiter of the "correctness" of any physical theory. It follows that a theory may never be "proved," since it is impossible to perform *all* experiments. Conversely, if such proof were possible, there would be no more

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* Received by the IRE, October 22, 1959.

[1] J. R. Pierce, "Relativity and space travel," Proc. IRE, vol. 47, pp. 1053–1061; June, 1959.

[2] H. L. Armstrong, "Comment on relativity and space travel," Proc. IRE, vol. 47, p. 1778; October, 1959.

need for the theory itself since the purpose of any theory is to predict the outcome of new experiments. The success of a theory may thus be judged by the manner in which it fulfills this objective. In contrast, only one physical observation is required to disprove a theory. If it can be shown that a prediction of the theory is in clear contradiction to the behavior of nature as observed by a well-performed experiment, the theory must be discarded.

If we are to retain our present concepts of the scientific method, we should treat the Theory of Relativity as any other theory. No amount of belief or disbelief and no lengthy emotional expression of philosophy will substitute for a careful analysis of the observed physical facts in relation to the predictions of the theory. To date, a great number of results predicted by the Theory of Relativity have been experimentally verified. No case of clear contradiction has yet been found. Whether the theory in its present form will continue to enjoy such remarkable success indefinitely is not the subject under discussion here. Few scientists today would be willing to attest to the infallibility of any theory. However, until now the Theory of Relativity has stood the test of many critical experiments which any potential critic would do well to ponder, and until such an experiment demonstrates a clear contradiction, the critic should content himself with devising new experiments.

Irrespective of the eventual outcome of experimental work, the Theory of Relativity will remain the remarkable contribution of a remarkable man and a monument to the ability of the scientific method to bring understanding to an area where there was none.

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A Simple General Equation for Attenuation*

The familiar equations for the attenuation of various kinds of transmission media all involve two basic kinds of dependencies. One is the intrinsic electrical properties of the conductors and dielectric; the other is the geometric configuration and scale of the cross section. It may not be generally appreciated that the attenuation of most of the media in which the waves are guided by conductors can be expressed by a single simple equation in which the two kinds of dependencies just mentioned are represented by separate and distinct coefficients. Once the equation is written, its coefficients may be readily evaluated by comparison with the usual equations for those cases for which the wave equations have been solved, or by correlation with experimental data. We believe this concept of a general equation is interesting, and that the equation itself is of considerable engineering usefulness.

One of the writers, Szekely, has produced a mathematical proof, using perturbation techniques, that the equation presented is indeed general and applies to all transmission systems having conducting surfaces parallel to an axis of a general orthogonal curvilinear coordinate system, along which the waves are propagating and in which the wave equations are separable. The proof will not be given here. It is based, however, on the assumption of good conductors and good dielectric materials. The equation applies, for example, to the attenuation per unit length of wire pairs, of coaxial conductors, of all transmission modes of waveguides of any shape of cross section, of strip lines, etc. It even applies to such structures as conical horns if the attenuation is expressed in nepers or decibels per unit length, per unit solid angle.

The attenuation per unit length of any transmission medium in the class just defined is given by

$$\alpha = \frac{M \dfrac{\sqrt{f}}{a}\left[A + B\left(\dfrac{f_c}{f}\right)^2\right] + D}{\sqrt{1 - \left(\dfrac{f_c}{f}\right)^2}}, \quad (1)$$

where:

D = constant depending only on the intrinsic properties of the dielectric,

M = constant depending only on the intrinsic properties of the dielectric and of the conducting material,

A, B = constants depending on the configuration (but not the scale) of the cross section, and on the transmission mode,

a = a selected linear dimension of the cross section specifying its size or scale, all other dimensions having fixed ratios to a,

f = transmitted frequency, and

f_c = cutoff frequency of the particular transmission mode on the given medium.

The constant D accounts for that part of the attenuation that is due to dissipation in the dielectric. In many cases where the dielectric is air or some other gas, this may be neglected. The remainder of this equation, representing the attenuation due to dissipation in the conductors, can be written in a normalized form:

$$\alpha_m \cdot a^{3/2} = \frac{M\sqrt{af}\left[A + B\left(\dfrac{f_1}{af}\right)^2\right]}{\sqrt{1 - \left(\dfrac{f_1}{af}\right)^2}}. \quad (2)$$

where $f_1 = af_c$.

A plot of $(\alpha_m \cdot a^{3/2})$ vs (af) gives one curve that is applicable to any scale of cross section, for a given medium of given shape of cross section and a given mode of transmission.

To apply (1) to a particular case, it is necessary to know the values of M, D, A, B and f_1. Since M and D depend only on the conducting and dielectric materials, they can be determined once for all transmission media employing particular materials, say copper and air. Their values are given by

$$D = \frac{\eta\sigma}{2} \quad (3)$$

$$M = \frac{1}{\eta}\sqrt{\frac{\pi\mu_m}{\sigma_m}}. \quad (4)$$

In these,

$\eta = \sqrt{\mu/\epsilon}$ = intrinsic impedance of the dielectric, where μ and ϵ are the absolute permeability and dielectric constant of the dielectric,

μ_m = permeability of the conducting material,

σ = conductivity of the dielectric, and

σ_m = conductivity of the conducting material.

For a vacuum and substantially for gases, $\eta = 120\pi = 377$ ohms. For dielectrics having a different dielectric constant than that of a vacuum, $\eta = 377/\sqrt{\epsilon_r}$, where ϵ_r is the relative dielectric constant.

It shall be noted that at frequencies well above cutoff, the portion of the attenuation constant caused by a lossy dielectric is very nearly a frequency independent constant, $(\alpha_D \cong D = \frac{1}{2}\mu\sigma)$; this is true for any geometric configuration, scale of cross section, or mode of transmission, provided that the conductance of the dielectric is constant and small. (In some dielectrics such as paper in paper-insulated telephone cables, σ appears to be a function of frequency.)

If rationalized MKS units are used, the attenuation given by (1) will be in terms of nepers per meter. Obviously, the attenuation may be converted to other units by multiplying M and D by suitable factors. Table I gives some values of M for copper conductors ($\sigma_m = 58 \times 10^6$ mhos per meter) and air dielectric, corrected for several combinations of units.

TABLE I

VALUES OF M FOR COPPER CONDUCTORS AND GAS DIELECTRIC

α	a	*f in cps.*	*f in KMC/sec.*
Nepers /meter	cm	69.1×10^{-9}	2.19×10^{-3}
db/meter	cm	600×10^{-9}	19×10^{-3}
db/ft	inches	72.1×10^{-9}	2.28×10^{-3}
db/mile	inches	0.38×10^{-3}	12

The constants A, B, and f_1 are obtainable from the equations given in the literature for most cases of interest. For cases not yet explored mathematically, their determination requires the application of electromagnetic wave theory, a process often difficult and too lengthy to discuss here. However,

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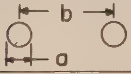
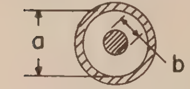
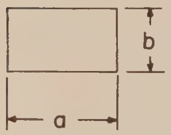
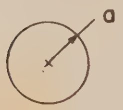
* Received by the IRE, October 30, 1959.

TABLE II

VALUES OF CONSTANTS DEPENDENT ON CONFIGURATION AND MODE

MEDIUM	MODE	CUTOFF		A	B
		$f_1 = af_c$	$\lambda_1 = \lambda_c/a$		
PAIR OF WIRES 	PRINCIPAL	(NOTE 1) 0	∞	$\dfrac{1}{\sqrt{1-(a/b)^2}\,\cosh^{-1} b/a}$	0
COAXIAL CABLE 	PRINCIPAL	0	∞	$\dfrac{1+a/b}{\log_e a/b}$ MIN = 3.59, WHEN $a/b = 3.59$	0
	NEXT HIGHER	$V/1.95$	1.95 APPROX	—	—
WAVEGUIDE-RECTANGULAR	TE_{10}	$\dfrac{V}{2}$	2	$\dfrac{a}{b}$	2
	TE_{mn}	$\dfrac{V}{2}\sqrt{m^2+n^2\dfrac{a^2}{b^2}}$	$\dfrac{2}{\sqrt{m^2+n^2\dfrac{a^2}{b^2}}}$	$\dfrac{a}{b}\cdot\dfrac{m^2+\dfrac{a}{b}n^2}{m^2+\dfrac{a^2}{b^2}n^2}\cdot\dfrac{2}{S_m S_n}$ (NOTE: $m=0,\ S_m=2$; $m\neq 0,\ S_m=1$ SIMILARLY FOR S_n)	$2\left(\dfrac{1}{S_m}+\dfrac{a}{bS_n}\right)-A$
	TM_{mn} ($m \geq 1,\ n \geq 1$)	$\dfrac{V}{2}\sqrt{m^2+n^2\dfrac{a^2}{b^2}}$	$\dfrac{2}{\sqrt{m^2+n^2\dfrac{a^2}{b^2}}}$	$2\dfrac{m^2+\dfrac{a^3}{b^3}n^2}{m^2+\dfrac{a^2}{b^2}n^2}$	0
WAVEGUIDE-CIRCULAR 	TE_{mn}	$\dfrac{V}{2\pi}\,r'_{mn}$	$\dfrac{2\pi}{r'_{mn}}$	$\dfrac{m^2}{(r'_{mn})^2-m^2}$	1
	TM_{mn}	$\dfrac{V}{2\pi}\,r_{mn}$	$\dfrac{2\pi}{r_{mn}}$	1	0
		NOTE: r_{mn} = n^{th} ROOT OF $J_m(r)$; r'_{mn} = n^{th} ROOT OF $J'_m(r)$			
NOTE 1: V = VELOCITY IN UNBOUNDED DIELECTRIC $= 1/\sqrt{\mu\varepsilon} = C/\sqrt{\mu_r\varepsilon_r}$					

as stated earlier, we have proved the existence of these constants for all cases in the previously defined class. The values of these constants for several common cases are given in Table II.[1]

It will be observed that (1) and (2) are analogous to the well-known equation,

$$\alpha = \frac{R}{2R_0} + \frac{GR_0}{2} \tag{5}$$

where R is the effective series ac resistance per unit length, G is the effective shunt conductance per unit length, and R_0 is the real part of the characteristic impedance. Obviously D is dimensionally similar to $GR_0/2$; and since $M\sqrt{f}$ is equal to the surface resistance of the conductor divided by η, the first part of the equation is dimensionally similar to $R/2R_0$.

The discussion above probably contains little that is new to those well versed in electromagnetic theory. However, we believe the engineering usefulness of the equation in the form given, plus the realization of its generality, justifies this communication.

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[1] Some of these values were obtained from equations given in G. C. Southworth, "Principles and Applications of Waveguide Transmission," D. Van Nostrand Co., New York, N. Y., pp. 94–95; 1950.

General Properties of the Propagation Constant of a Nonreciprocal Iterated Circuit*

Complementing an effort to introduce nonreciprocal loss into a microwave iterated circuit, a theoretical determination has been made of the behavior of the propagation constant of a general iterated circuit containing nonreciprocal components. This circuit might find use in a traveling-wave tube or parametric amplifier.

The model examined was an infinitely long chain of identical two-port networks, each specified by the matrix

$$(Z) = \begin{pmatrix} z_{11} & z_{12} \\ z_{21} & z_{22} \end{pmatrix},$$

where $z_{12} \neq z_{21}$ since each network contains nonreciprocal components. Voltages (and currents) to the right and left of each network are assumed to be related by the factor $e^{j\Theta}$ and the problem is to examine the nature of Θ.

The voltages and currents of the system are related by

$$\begin{pmatrix} V_n \\ V_{n+1} \end{pmatrix} = (Z)\begin{pmatrix} I_n \\ -I_{n-1} \end{pmatrix} \tag{1}$$

where n refers to the nth network and $e^{j\Theta} = V_{n+1}/V_n = I_{n+1}/I_n$. Eq. (1) may be expanded and put into the form

$$z_{12}e^{j\Theta} + z_{21}e^{-j\Theta} = z_{11} + z_{22}. \tag{2}$$

Use is made of the following definitions

$$\frac{z_{21}}{z_{12}} = e^{2(jb-\psi)},$$
$$\phi = b + (\text{angle of } z_{12}),$$
$$\Theta = \theta + j\chi,$$
$$x = 1/2\,\frac{\text{Im}\,(z_{11}+z_{22})}{|z_{12}|},$$
$$r = 1/2\,\frac{\text{Re}\,(z_{11}+z_{22})}{|z_{12}|},$$
$$P_c(x) = e^{\psi}(r\cos\phi + x\sin\phi),$$
$$P_s(x) = e^{\psi}(r\sin\phi - x\cos\phi). \tag{3}$$

After a little algebra, (2) may be written

$$\cos(\theta - b)\cosh(\chi - \psi) = P_c(x)$$
$$\sin(\theta - b)\sinh(\chi - \psi) = P_s(x). \tag{4}$$

Finally, conservation of energy requires that

$$r \geq 1/2\,\left|1 + e^{2(j\phi-\psi)}\right| \geq 0. \tag{5}$$

Although all quantities are basically a function of frequency, it will be convenient to consider x as an independent variable and r as a parameter. Although specific values of x and r do not determine the other quantities uniquely, they do determine upper and lower bounds on the other quantities. The cases of $r=0$ and $r>0$ will now be treated.

1) $r=0$ (lossless case). From (5), $\psi=0$, $P_c(x)=x$, and $P_s(x)=0$, so that (4) becomes

$$\cos(\theta - b)\cosh\chi = x$$
$$\sin(\theta - b)\sinh\chi = 0. \tag{6}$$

* Received by the IRE, October 19, 1959.

Eq. (6) has the simultaneous solution

$$\left.\begin{aligned}\cos(\theta - b) &= x\\ \chi &= 0\end{aligned}\right\} -1 \leq x \leq 1,$$

$$\left.\begin{aligned}\theta - b &= m\pi\\ \cosh\chi &= (-1)^m x\end{aligned}\right\} |x| \geq 1.$$

χ and $\theta - b$ are plotted vs x as the solid curves in Figs. 1 and 2 where it is understood that $\psi = 0$. The structure has a pass band from $-1 \leq x \leq 1$. Within this range, the loss parameter χ is zero and the phase parameter θ varies from $m\pi + b$ to $(m \pm 1)\pi + b$. For x above 1 and below -1, the loss parameter is high and the phase parameter is $m\pi + b$. The significant difference between the nonreciprocal and reciprocal cases is that in the latter x is an even function of θ, *i.e.*, $b = 0$. In the former case, this is no longer true. At $\theta = 2\pi m$, x is not 1 but $\cos b$. Thus, for a nonreciprocal circuit, the propagation constants of the space harmonics will depend on the direction of propagation. A plot of x vs θ would look like Fig. 1 except that the curve shown in Fig. 1 would be shifted to the left or right of the ordinate by an amount b. If b is not a constant but a function of x, the situation is further complicated.

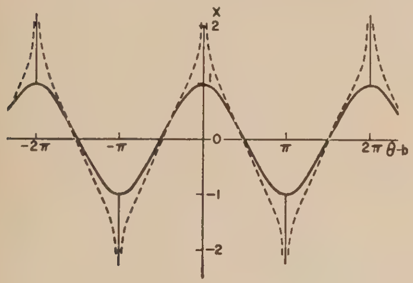

Fig. 1.

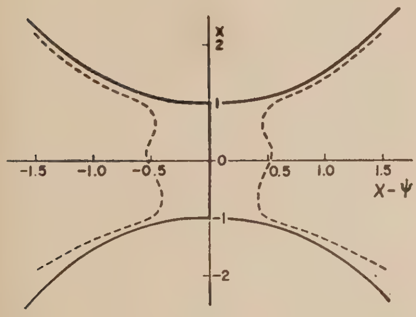

Fig. 2.

2) $r > 0$ (lossy case). For $r > 0$, (5) indicates that it is only possible to determine ϕ and ψ to within a band of values whose upper and lower limits may be calculated. Thus, for specific values of r and x, P_c and P_s may be determined to within a band whose upper and lower limits may be calculated. Nevertheless, from this information, it is possible to predict the general behavior of the loss and phase parameters. Typical plots of these parameters vs x are shown as the dotted curves in Figs. 1 and 2.

As an aid in determining these plots, we write (4) in the form

$$\sin^2(\theta - b) = P_c^2(x)\tan^2(\theta - b) - P_s^2(x),$$

$$\sinh^2(\chi - \psi) = P_c^2(x)\tanh^2(\chi - \psi) + P_s^2(x) \quad (7)$$

and note the intersection of the left and right hand sides of each equation as P_c and P_s are given their extreme values holding r fixed and varying x.

The behavior of χ and θ for $r > 0$ is more or less an expected extension of the $r = 0$ case except that now the loss parameter depends on the direction of propagation since $\psi \neq 0$. A plot of χ vs x would be the plot of Fig. 2 shifted to the left or right of the ordinate by an amount ψ. If ψ is a function of x, the situation is further complicated.

Two points of practical importance should be noted about an iterated nonreciprocal circuit used as a traveling-wave tube circuit. First, in a traveling-wave tube, $\theta = \beta L$ where L is the periodic length. In order to get interaction with the electron beam over a maximum of the pass band (from $x = -1$ to $+1$), at midband (frequency corresponding to $x = 0$) β must be approximately equal to the plasma slow-wave propagation constant and $\theta = \theta_{x=0}$. For the reciprocal case, $\theta_{x=0}$ is very close to an odd multiple of $\pi/2$ so that L is determined. In the nonreciprocal case, $\theta_{x=0} =$ (odd multiple of $\pi/2$) $+ b$ and theoretically may be any angle. Thus, L is not restricted and may be chosen so as to optimize some parameter such as interaction impedance.

Secondly, it can be true that the addition of loss broadens the band of circuit-wave interaction with the electron beam (see Fig. 1, dotted curves). However, the attendant forward-wave loss negates the desirability of doing this. However, in a nonreciprocal circuit, it is theoretically possible to introduce ψ in such a way that the forward loss is small. At the same time, the backward loss increases, which is usually a desirable circuit property.

The author wishes to acknowledge the valuable aid of S. Sensiper of Hughes Aircraft Co. who suggested the problem and who provided subsequent stimulating discussions.

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Parametric Amplifier Antenna*

A number of circuit configurations have been reported[1] for employing voltage variable capacitors as the active element in a parametric amplifier. One form, described by Harris[2] and others, utilizes a coaxial distributed structure to provide, at the same time, appropriate resonant conditions for both the signal and the so-called idler frequency components. In this mode of operation the input signal and the output are at the same frequency f_s. The pumping energy source may be at $2f_s$, $4f_s \cdots$ etc., while the idler will have a corresponding value of f_s, $3f_s \cdots$. A number of advantages can be derived by realizing this circuit in a balanced form and incorporating the resulting structure inside of a half wave dipole as shown in Fig. 1. The amplifier consists of the outer cylinder of length L which serves as an antenna, and an inner coaxial conductor, diameter D', supported at the center by an RF connector and low loss dielectric spacers as shown. Each end of the center conductor is connected to the corresponding end of the antenna through parametric diodes (HPA 2800) at C and C'. The antenna is split at the mid-point to provide dc isolation for the diode bias paths. A thin dielectric layer between the dipole sections and the central supporting sleeve serves as an RF bypass path for antenna currents. The pumping signal is applied to both diodes in phase through the inner conductor at P_1. With the center conductor at dc ground, either through the generator or a suitable transmission line stub, diode bias voltages are applied at $B+$ and $B-$. In operation the interior coaxial region serves as a resonant storage volume for both the signal and idler components. The output is taken at P_2 from loop S through a suitable network which passes f_s while rejecting f_i.

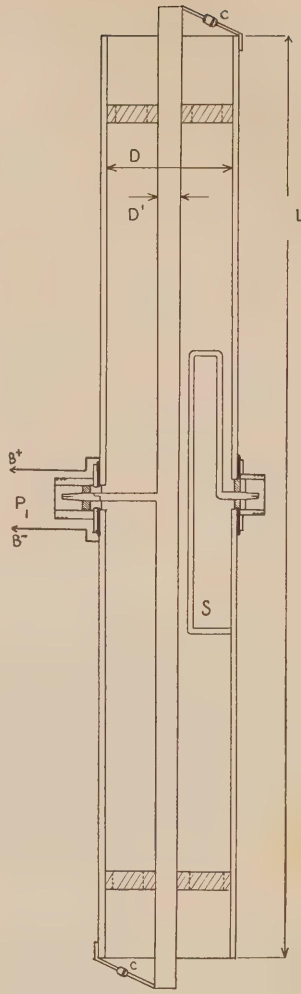

Fig. 1—Cross-sectional view of parametric amplifier antenna or "parant."

Fig. 2 shows the inner construction of a unit designed for use at 220 mc. Fig. 3 is the assembled antenna-amplifier dipole. It is necessary that the physical length of the

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* Received by the IRE, October 29, 1959. The work described has been carried out under the sponsorship of the Electronics Research Directorate, Air Force Cambridge Res. Center.

[1] A. Uhlir, Jr., "The potential of semiconductor diodes in high frequency communications," Proc. IRE, vol. 46, pp. 1099–1115; June, 1958.
B. Salzberg and W. E. Sard, "A low-noise wide-band reactance amplifier," Proc. IRE, vol. 46, p. 1303; June, 1958.

[2] F. S. Harris, "The parametric amplifier," CQ, vol. 14, November, 1958.

antenna cylinder be adjusted for the desired center operating frequency while at the same time the coaxial system is resonant at f_s and an odd multiple of f_s. Since the free resonant length of an antenna is significantly less than λ/2 the interior system would appear to have less than its requisite electrical length. It has been found, however, that with the antenna units investigated to date an adjustment of fringing and diode capacitance has been sufficient to achieve the simultaneous resonance conditions without the use of an internal dielectric septum. Antenna-amplifier gain, relative to a passive dipole of the same length and diameter and measured as a function of frequency, is shown in Fig. 4.

In addition to the advantage of a potentially low noise figure such as is common to reactive parametric amplifiers, this arrangement provides a low impedance output at a coaxial connection in the neutral plane of the antenna. Complications in construction arising from the use of a split outer conductor can be avoided by separating the inner conductor into two sections at the center and applying the pumping and bias voltages through a twin coaxial connector instead of the type *N* as used in this version.

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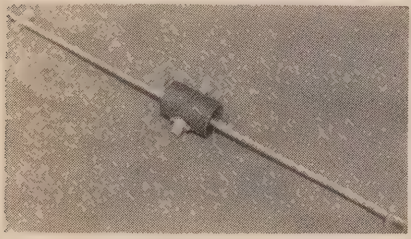

Fig. 2—Antenna center conductor showing output loop and coaxial connectors.

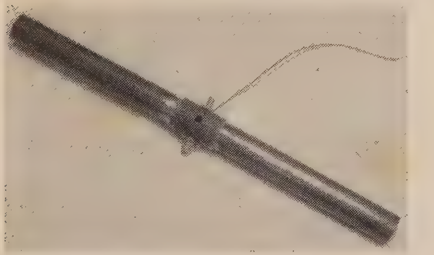

Fig. 3—Assembled antenna amplifier dipole.

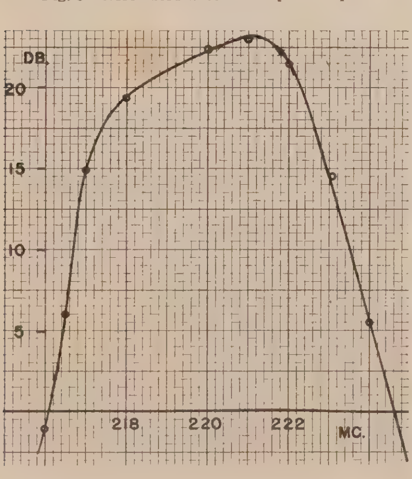

Fig. 4—Antenna amplifier gain relative to passive dipole having the same length and diameter. Pumping source frequency and dc bias adjusted at each point for maximum gain.

Superdirectivity*

Kock[1] in his interesting paper on "Related Experiments with Sound Waves and Electromagnetic Waves" credits Schelkunoff[2] with the first discussion of superdirectivity in aerial arrays. Though Dr. Schelkunoff's paper is of basic importance in this field, investigation of the phenomenon commenced much earlier. The first demonstration of the possibility of superdirectivity that we know of was published in 1922 by C. W. Oseen.[3] Reference to four other papers prior to that of Schelkunoff was given by us in a previous paper.[4] In the bibliography appended to that paper, we listed all the work on superdirectivity then known to us; the quite impressive total of twenty-eight items resulted. In view of the continued interest in this subject it may be of value to bring this listing up to date, as attempted in the bibliography below. For the Goward reference [1] we are indebted to Mr. J. D. Lawson of the Atomic Energy Research Establishment at Harwell.

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R. G. Medhurst,
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Author's Comment:[5]

I feel that Oseen[3] discussed the possibility of superdirectivity, whereas Schelkunoff[2] and Franz [28] demonstrated a feasible method of approach to its realization. Schelkunoff U. S. Pat. No. 2,286,839 on this subject was applied for on December 20, 1939; it was issued on June 16, 1942. I am indebted to Dr. Franz for the receipt of reprints of two papers of his [28, 30] which appeared during the war and which I failed to reference. The second [30] refers to still another author on superdirectivity: A. Fradin, *J. O. A. Ph.*, Leningrad, Russia, vol. 9, p. 1161; 1939.

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* Received by the IRE, November 4, 1959.

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[2] S. A. Schelkunoff, "A mathematical theory of linear arrays," *Bell Sys. Tech. J.*, vol. 22, pp. 80–107; January, 1943.

[3] C. W. Oseen, "Die Einsteinsche, Nadelstichstrahlung und die Maxwellschen Gleichungen," *Ann. der Phys.*, vol. 69, pp. 202–204; 1922.

[4] A. Bloch, R. G. Medhurst, S. D. Pool, "A new approach to the design of super-directive aerial arrays," *Proc. IEE (London)*, pt. III, vol. 100, pp. 303–314; September, 1953.

[5] Received by the IRE, November 25, 1959.

Parallel Field Excitation*

AT-cut circular quartz plates or lenses are used for the control of precision oscillators in the range of 500 to 2500 kc.

The major requirements are: high Q, freedom of unwanted responses, and a good frequency-temperature behaviour.

As the inductance of these crystals is low, it is necessary to reduce by all means the resistance of the crystals in order to obtain high Q values. Good crystals, however, have a very low resistance of about one to five ohms. This complicates the design of the oscillator from the point of view of impedance matching.

As a result of recent work performed at the Paris Observatory, as well as at Oscilloquartz Dept. of Ebauches S.A. at Neuchatel, Switzerland, the electric parameters of the crystals were altered by application of an electric field parallel to the major surfaces of the crystal; this is instead of having it normal to the surfaces, as it is usually done for the excitation of thickness-shear vibrations.

There are two main points to consider when the parallel field method is applied:

1) Inductance and resistance are rising, but the former rises quicker than the latter; thus the Q value increases.
2) The resistance of unwanted responses is highly increased, especially that of unwanted face shear modes.

For one-mc fundamental-mode plated lenses of about 27-mm diameter, Q values between 6 and $8 \cdot 10^6$ have been obtained. For 0.5-mc fundamental-mode plated lenses of about 38-mm diameter, the Q is approximately 8 to $10 \cdot 10^6$. For both types, the resistance has values between 45 and 80 ohms, and the inductance is approximately 50 times higher than the inductance of crystals excited by a field normal to the surfaces.

Much higher Q's are obtained with *non-plated* crystals excited by the parallel field. Depending upon the choice of the geometry of the electrodes and of the air gap, the Q's of 0.5- and 1-mc lenses are approximately $20 \cdot 10^6$.

All the measurements mentioned above have been made at room temperature.

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* Received by the IRE, November 6, 1959.

Theoretical Hysteresis Loops of Thin Magnetic Films*

The theoretical static behavior of single domain thin magnetic films can be determined on the basis of a few hypotheses:

1) The magnetization vector has a constant amplitude M_s.
2) It lies in the plane of the film.
3) The total energy per unit volume of the film is

$$E = K \sin^2 \theta - HM_s \cos (\phi - \theta) \qquad (1)$$

The first term in (1) is the uniaxial anisotropy energy, where K is the anisotropy constant and θ the angle between the magnetization vector and the preferred direction of magnetization (easy direction). The second term is the energy of magnetization in the applied field of amplitude H and of direction ϕ.

Magnetization curves obtained from (1) are analyzed as a function of ϕ by Stoner and Wohlfarth[1] and for crossed fields by Smith.[2] Chu and Singer[3] give a graphical method, based on these energy considerations, for the determination of theoretical hysteresis loops. This communication gives a simple analytical method as well as a graphical construction more accurate and easier than the first method, which is sometimes difficult because of the flatness of the energy minimum. As is known, the magnetization assumes the direction in which the total energy E is a minimum.

$$\frac{\partial E}{\partial \theta} = 0; \quad \frac{\partial^2 E}{\partial \theta^2} > 0. \qquad (2)$$

Two stable orientations exist for certain values of the field. By a continuous variation of the field vector, a jump occurs when the present minimum disappears; this case is realized when

$$\frac{\partial^2 E}{\partial \theta^2} = 0. \qquad (3)$$

An analytical expression for the theoretical hysteresis loop, given by (1) and (2), is easy to obtain. The easy and hard directions are called x and y. The projections H_x and H_y of the field and the projections M_x and M_y of the magnetization are considered. M_x and M_y are related to the angle θ by

$$M_x = M_s \cos \theta; \quad M_y = M_s \sin \theta. \qquad (4)$$

Reduced variables can be introduced in order to get dimensionless equations:

$$h_x = \frac{H_x M_s}{2K}; \quad h_y = \frac{H_y M_s}{2K};$$
$$m_x = \frac{M_x}{M_s}; \quad m_y = \frac{M_y}{M_s}. \qquad (5)$$

Combination of (1), (2), (4) and (5) gives the system:

$$\boxed{\begin{aligned} & m_x^2 + m_y^2 = 1 \\ & \frac{h_x}{m_x} - \frac{h_y}{m_y} = -1. \end{aligned}} \qquad (6)$$

The simplest way to compute hysteresis loops in the easy and hard directions, by means of these equations, is to consider m_x or m_y as the independent variable and h_y or h_x as a parameter, and then to compute h_x or h_y. The four main cases are shown in Fig. 1(a) below, and Fig. 1(b), next page. The jumps in the first two curves occur when $\partial h_x / \partial m_x = 0$ which, combined with (6), gives

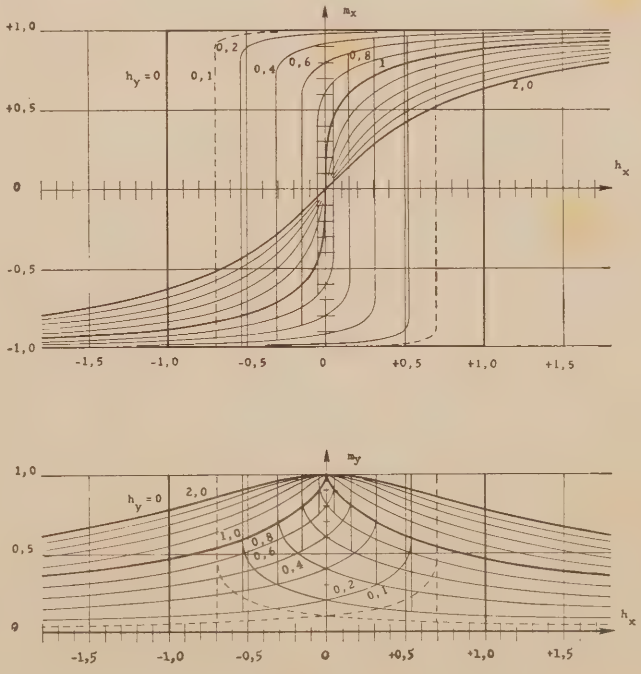

Fig. 1(a)

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[1] E. C. Stoner and E. P. Wohlfarth, "A mechanism of magnetic hysteresis in heterogeneous alloys," *Phil. Trans. Roy. Soc., A*, vol. 240, pp. 599–642; 1948.

[2] D. O. Smith, "Static and dynamic behaviour of thin permalloy films," J. Appl. Phys., vol. 29, pp. 264–273; March, 1958.

[3] K. Chu and J. R. Singer, "Thin film magnetization analysis," Proc. IRE, vol. 47, pp. 1237–1244; July, 1959.

* Received by the IRE, November 2, 1959.

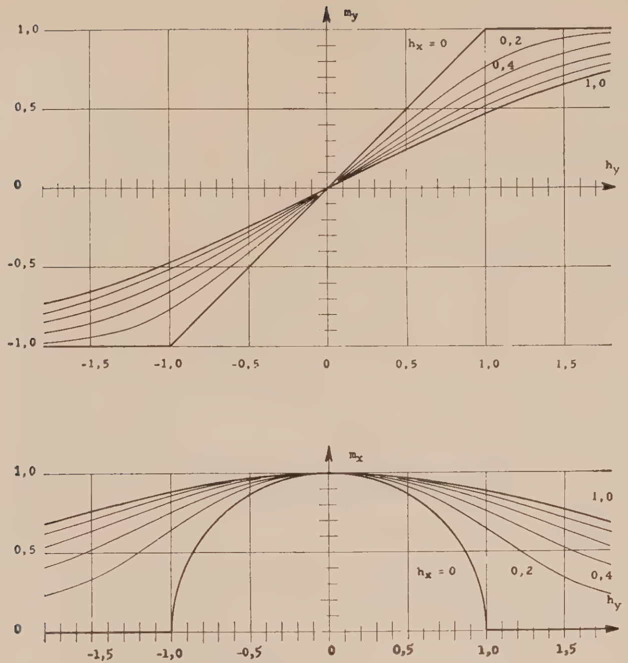

Fig. 1(b)

Fig. 1—Magnetization projection m_x and m_y. (a) As a function of the field h_x in the easy direction and with the field h_y in the hard direction as parameter; (b) as a function of the field h_y in the hard direction and with the field h_x in the easy direction as parameter.

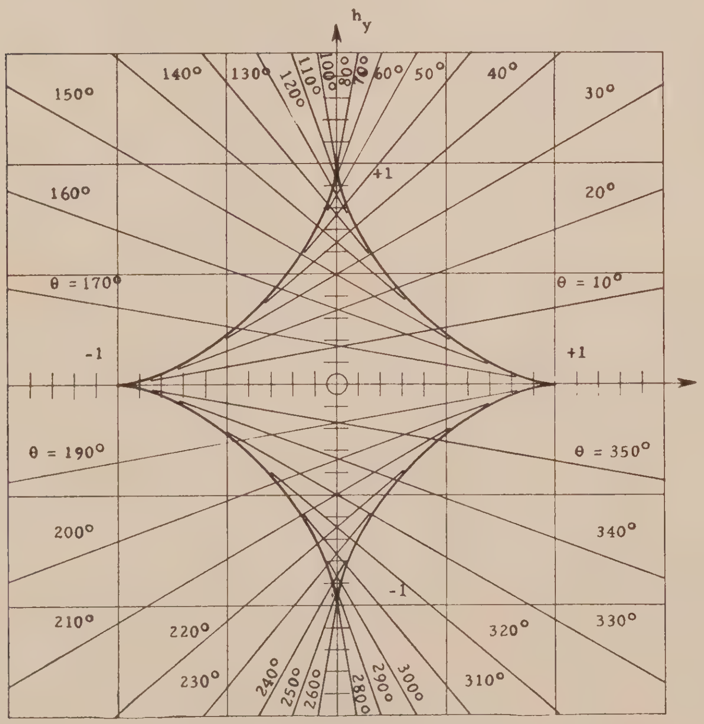

Fig. 2—Critical curve and geometrical construction of the magnetization direction θ.

the relation

$$h_x^{2/3} + h_y^{2/3} = 1. \qquad (7)$$

This equation represents the critical curve. The magnetization just before a jump is

$$m_x = h_x^{1/3}; \qquad m_y = h_y^{1/3}. \qquad (8)$$

In the easy direction, the curves are reversible when $h_y \geq 1$. The initial susceptibility in the reduced curves is then

$$\left.\frac{\partial m_x}{\partial h_x}\right|_{h_x=0} = \frac{1}{h_y - 1}.$$

In the hard direction, the curves are always reversible, and the initial susceptibility is

$$\left.\frac{\partial m_y}{\partial h_y}\right|_{h_y=0} = \frac{1}{h_x + 1}.$$

An essential property of (6) is the linear dependence of h_x and h_y for a given value of m_x, m_y or of the direction θ of the magnetization vector. Furthermore, it can be shown[4] that all the straight lines in the (h_x, h_y) plane are tangential to the critical curve (7). This property can be used for the graphical determination of hysteresis loops under various conditions (Fig. 2), as first proposed by Slonczewski.[5] The straight line going through the point (h_x, h_y) and tangential to the critical curve forms, with the x axis, an angle θ equal to the angle formed by the magnetization vector with the easy direction.

Experimental curves agree very well with the theoretical curves obtained under the simplified initial hypotheses, provided single domain structure and rotational processes only take place. This is the case for the reversible curves shown in Fig. 3.

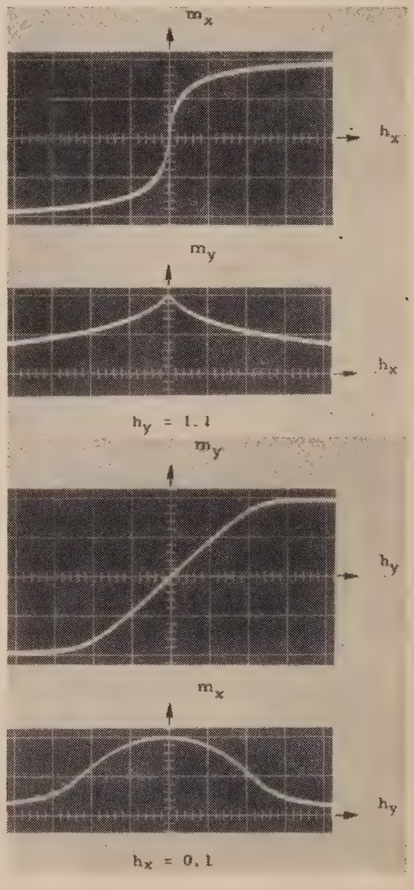

Fig. 3—Experimental M-H loops of a Ni-Fe film of about 80-20 composition show rotational and reversible behavior at low frequency (500 cps).

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[4] P. Franklin, "Advanced Calculus," McGraw Hill Book Co., Inc., New York, N. Y., p. 343: 1944.

[5] J. C. Slonczewski, "Theory of magnetic hysteresis in films and its application to computers," IBM Rept. No. RM 003.111.224, October 1, 1956 (unpublished).

Narrow-Band Filtering of Random Signals*

The misconception that the output of a narrow-band filter is more nearly Gaussian than some corresponding non-Gaussian random input appears to be widespread. The incorrectness of this concept is demonstrated by the following examples.

First, consider the random process consisting of the pure cissoids,

$$x(t) = e^{2\pi j(ft+\phi)}, \quad -\infty < t < \infty,$$

where the frequency f is a random variable with arbitrarily given probability distribution,

$$\Pr\{f \le \lambda\} = F(\lambda), \quad -\infty < \lambda < \infty,$$

and the random phase ϕ is uniformly distributed on the unit interval. The process thus defined[1] is stationary in the wide sense, with autocovariance easily seen to be

$$\langle x(t_1)\overline{x(t_2)}\rangle = \int_{-\infty}^{\infty} e^{2\pi j\lambda(t_1-t_2)}dF(\lambda). \tag{1}$$

[Note that any (unit power) power spectrum may be thus realized.] If this process is applied as input to a filter with transfer function

$$\begin{aligned} Y(2\pi jf) &= 1 \quad f' < f \le f'', \\ &= 0 \quad \text{otherwise}, \end{aligned} \tag{2}$$

then the output, renormalized to unit power, has at any fixed time the form,

$$\begin{aligned} \Delta^{-1/2}e^{2\pi j\theta} &\text{ with probability } \Delta, \\ 0 &\text{ with probability } 1-\Delta, \end{aligned}$$

where $\Delta = F(f'') - F(f')$, and where θ is a random variable uniformly distributed on the unit interval. This distribution of the output does not approximate the (complex) unit normal distribution in any reasonable sense as $f'' - f' \to 0$. The analogous real process and filter also give rise to a non-Gaussian output distribution.

A more striking example is provided by

$$x(t) = n^{-1/2}\sum_{\nu=1}^{n} e^{2\pi j(f_\nu t+\phi_\nu)}, \quad -\infty < t < \infty, \tag{3}$$

where f_ν, ϕ_ν, $\nu = 1, \cdots, n$ are mutually independent random frequencies and phases, respectively, each distributed as in the example above. The autocovariance of process (3) is given by (1), as before. If n is large, then the distribution of $x(t)$ of (3) at any fixed time will be nearly Gaussian, by the central limit theorem. If now f' and f'' are chosen so that $n\Delta$ is moderately small (say $n\Delta < 0.25$) then the output of filter (2) will have at any fixed time the form (again, renormalized to unit power)

$$\begin{aligned} 0 &\text{ with probability } 1-n\Delta+O((n\Delta)^2) \\ (n\Delta)^{-1/2}e^{2\pi j\theta} &\text{ with probability } n\Delta+O((n\Delta)^2) \\ (\text{other}) &\text{ with probability } O((n\Delta)^2), \end{aligned}$$

with Δ and θ as before. Thus a random signal whose distribution at any fixed time is nearly Gaussian is converted by narrow-band filtering to one whose variables are much less Gaussian.

It may be argued that the processes described above are not ergodic and the author is willing to admit the possibility that narrow-band filtering of a non-Gaussian stationary (wide sense) process which is ergodic in the wide sense[2] might give a process whose variables are individually more nearly Gaussian. However, the above examples indicate that a proof will have to be more delicate than the heuristic arguments usually given. (In these arguments, small correlation is confused with small stochastic dependence.)

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* Received by the IRE, October 22, 1959.

[1] J. L. Doob, "Stochastic Processes," John Wiley and Sons, Inc., New York, N. Y., p. 525; 1953. It is to be emphasized that each sample function of the process is a pure cissoid, of fixed frequency and phase, extending indefinitely in time. The random element is the choice of frequency and phase.

[2] By this we mean a process whose sample function autocorrelations (time average) are equal to the process autocovariance (statistical average) with probability 1; the definition of Doob is different. See J. L. Doob, *op. cit.*, pp. 461–464, 493–497.

Rapid Periodic Fading of Medium Wave Signals*

The occurrence of a peculiar type of rapid fading, called "flutter phenomenon," in broadcast signals have been reported by Subba Rao and Somayajulu.[1] They observed this type of fading regularly on the 41-m and 61-m bands and occasionally on the 19-m band, but never on the medium wave band. Recently, Yeh and Villard[2] reported the occurrence of a more rapid fading of signals in the 41-m band propagating over long paths crossing the magnetic equator.

Using a superheterodyne broadcast receiver, the AVC system of which was disconnected, and a recording millivoltmeter, it has been possible to record the same type of rapid fading of signals on the medium wave as well as short wave bands. A few typical records are reproduced here. The particulars of these records are as follows: Fig. 1(a) shows fading of transmission in the 19-m band from Karachi, received at 1935 hours Indian Standard Time (IST) on March 3, 1959. Fig. 1(b) shows the same in the 61-m band from Madras, received at 1845 hours IST the same day. Fig. 2(a) is a record of such fading of signals at 280.4-m received from Delhi at 2027 hours IST, also the same day. Fig. 2(b) represents another such record of the 280.4-mc signals obtained at 1912 hours IST on March 16, 1959 and

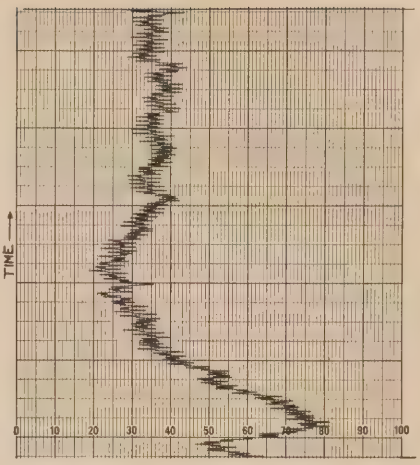

Fig. 1(a)

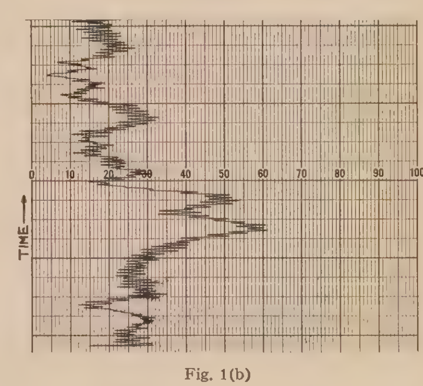

Fig. 1(b)

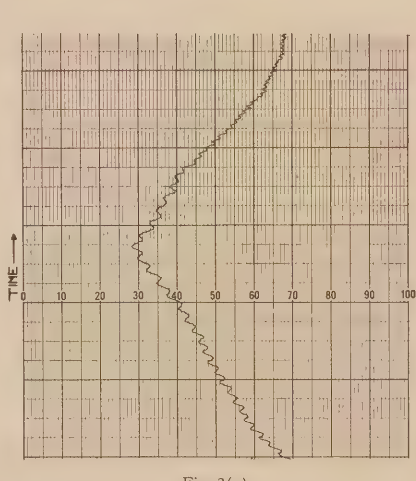

Fig. 2(a)

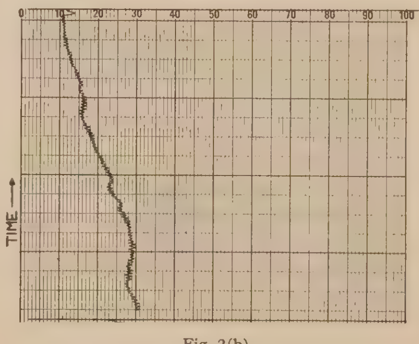

Fig. 2(b)

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* Received by the IRE, October 22, 1959.

[1] N. S. Subba Rao and V. V. Somayajulu, "A peculiar type of rapid fading in radio reception," *Nature*, vol. 163, p. 442; March, 1949.

[2] K. C. Yeh and O. G. Villard, Jr., "A new type of fading observable on high-frequency radio transmissions propagated over paths crossing the magnetic equator," Proc. IRE, vol. 46, pp. 1968–1970; December, 1958.

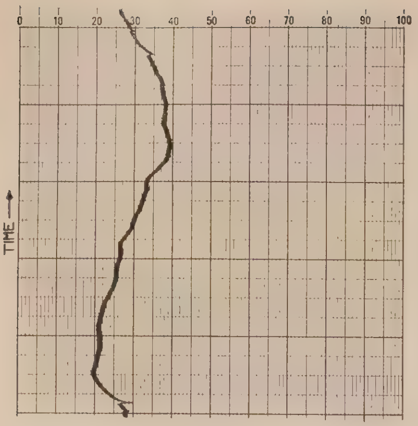

Fig. 2(c)

Fig. 2(c) shows a more rapid fading of the same signals at 1850 hours IST on March 12, 1959. On the time axis, four large divisions represent one minute.

It may be noted that the rate of fading of the medium wave signals is of the same order as that of the short wave signals, namely, about 1.5 to 3 cps. No known mode of propagation can account for such a rate of fading at this wavelength. Further records are being made.

The gift of a Varian type G-10 graphic recorder from the U. S. Government under the India Wheat Loan Educational Exchange Scheme is gratefully acknowledged.

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Report on the AGU Study of the Metric System in the United States

The American Geophysical Union's Special Committee for the Study of the Metric System in the United States has noted the recent publication of our "Letter to the Editor" and its accompanying Questionnaire in the PROCEEDINGS.[1]

We wish to express our sincere appreciation for the courtesy of the IRE in presenting this matter to its readers. We wish also to thank your members who aided the Committee by a generous response of completed questionnaires. Many of the replies included letters containing helpful suggestions and offering financial assistance if requested.

Those readers who have access to the September, 1959, *Transactions of the American Geophysical Union* will find there a full report of the Committee, together with an analysis of the replies to the Questionnaire received up to July. At this date, three months later, 1080 have been analyzed. The scientific and engineering field was rather well covered by publication last spring of the Letter or Questionnaire, or both, in eight of the leading journals and magazines of the United States. Briefly, to the most significant question as to whether it would be desirable to replace the English System with the Metric as the "only official system" of weights and measures in the United States, ninety per cent have replied in the affirmative. The average suggested period of transition was about 22 years; this indicates agreement with the Committee on the necessity for a long transition period to avoid economic dislocation through education in the schools, through a normal retirement of presently active older personnel, and through the normal obsolescence of existing equipment.

The Congress of the United States, for the first time in nearly thirty years, is faced with a decision on metric legislation, recently introduced in both Houses. House Bill, HR7401, May, 1959, by Mr. Brooks of Louisiana, and Senate Bill, S2420, July, 1959, by Mr. Neuberger, both call for a feasibility study of the problem by an appropriate Government agency, with fund authorization. A third action of interest is the introduction in July, 1959, by Representative Fulton, of House Concurrent Resolution 364 which would place the Congress on record in favor of the Metric System.

It is apparent that the United States must soon decide whether to change over gradually, during the next generation, to a far simpler and more logical system of weights and measures, or to continue to live in comparative isolation with the remaining ten per cent of the world's population not yet under the Metric System.

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* Received by the IRE, November 1, 1959.

[1] F. W. Hough, "AGU Committee for the Study of the Metric System in the United States," PROC. IRE, vol. 47, p. 584; April, 1959.

Noise Spectrum of Phase-Locked Oscillators*

The fundamental parameter that best describes a phase-locked klystron is the noise spectrum of the oscillator in the phase-locked condition.[1] Some time ago a program for studying the sources of noise in phase-locked oscillators was established in the Microwave Spectroscopy Laboratory of the Research Laboratory of Electronics, Massachusetts Institute of Technology. The following remarks are a summary of the results of this project at its termination.

Since the first demonstration[2] of the simple utility of phase-locking klystron techniques in the microwave region, there has been considerable concern about the purity and validity of the resulting spectrum. Sources of noise, either amplitude-modulation noise or phase-modulation noise, can arise at many points in the servo-control loop. The importance of the various sources of noise is most convincingly demonstrated by experimental measurement. For this reason, a test facility consisting of two Felch oscillators,[3] at 1 mc and 5 mc, was built; active tube multipliers, multipling to 300 mc and 700 mc, were constructed; and electronic phase-locking equipment for K-band and X-band klystrons was assembled or constructed. The final system is shown in the block diagram of Fig. 1. It consists essentially of a silicon-diode harmonic generator, balanced mixer, 455-kc IF amplifier, phase demodulator, dc amplifier, and phase-correcting network to the klystron repeller. Previous phase-stabilization circuits measured in this laboratory have indicated a carrier noise level of approximately 60 db/cps.[4] It was our intention to use the measurements for comparing the noise amplitude as a function of the multiplication ratio and as a function of the low-frequency crystal-reference oscillator frequency.

Two klystrons were stabilized in this fashion and were beaten against each other in a superheterodyne receiver; the resulting beat note (arising from a small difference in the fundamental crystal-oscillator frequencies) could be displayed on an oscilloscope and the carrier-to-noise ratio could be analyzed with a General Radio harmonic distortion analyzer.

Unfortunately, when the system reached satisfactory operating condition, it was found that even with a frequency multiplication of 10,000 from a low-level Felch crystal oscillator the noise power per frequency interval was much too low to be measured on the distortion analyzer. The clarity of the beat note under these conditions can be seen from Fig. 2. The video bandwidth of the presentation system was 4 mc, so that the photograph shows the total noise signal. Although no definite measurements are available, the noise level must be less than 100 db below carrier per cps.

We conclude that with reasonably decent feedback electronics, the noise arising from the fundamental crystal oscillator or the multiplier chain is negligibly small, even with a frequency multiplication ratio of 10,000. Stated another way, this means that there should be no difficulty in operating a phase stabilizer from a 10-mc crystal in the 100-kmc frequency region, and so on.

There is no doubt that the system as we have operated it is far from optimum. The IF frequency is low. This was governed by a desire to have it less than the fundamental

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* Received by the IRE, October 22, 1959. This work was supported in part by the U. S. Army (Signal Corps), the U. S. Air Force (Office of Scientific Research, Air Research and Development Command), and the U. S. Navy (Office of Naval Research).

[1] M. W. P. Strandberg, Letter to the Editor, *Radiotek. i Elektron.*, vol. 3, p. 1220; September, 1958.

[2] M. Peter and M. W. P. Strandberg, "Phase stabilization of microwave oscillators," PROC. IRE, vol. 43, pp. 869–873; July, 1955.

[3] F. P. Felch and J. O. Israel, "A simple circuit for frequency standards employing overtone crystals," PROC. IRE, vol. 43, pp. 596–603; May, 1955.

[4] M. W. P. Strandberg, "Phase stabilization of microwave oscillators," PROC. IRE, vol. 44, p. 696; May, 1956.

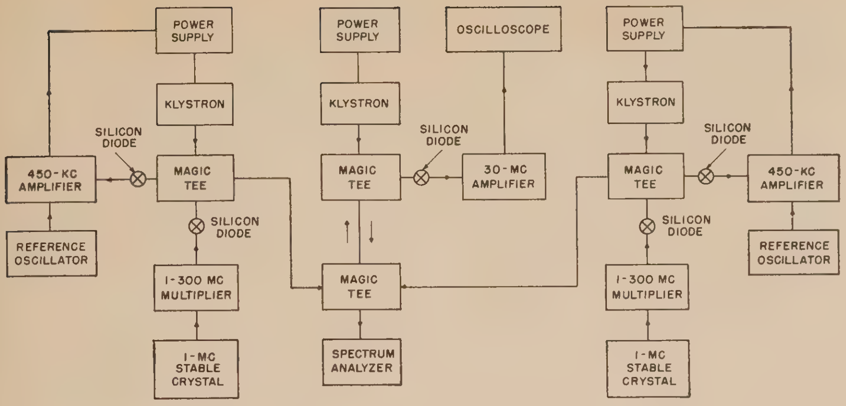

Fig. 1—Phase-locked stabilization of microwave frequencies.

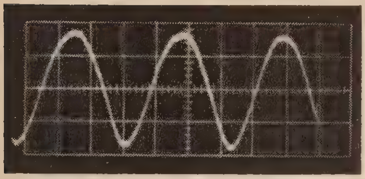

Fig. 2—Beat note of two phase-locked klystrons.

crystal-oscillator frequency. Thus the system was limited to a locking range of less than 0.5 mc; the hold in range, however, was approximately 10^4 mc. Even with this relatively poor design, these experiments have removed any doubt about the feasibility of phase-locking techniques—in the face of the argument that in the process a catastrophic amount of noise will also be generated. There is no doubt that this noise limitation will be met as the multiplication ratio becomes greater. As far as we can foresee, a multiplication ratio of 10,000 should be quite sufficient for most purposes, and should still be adequately remote from the multiplication ratio that would yield a noisy spectrum in the stabilized klystron output.

The over-all, long-time, relative phase stability of the two systems has not been studied because a study of the phase stability of the particular multipliers used would not be of general interest. The secular phase shift in the multiplier output can be reduced by limiting the number of multiplier stages and carefully controlling the input signal, temperature, operating potentials, and so forth. It would seem that a single-stage multiplier would be ideal for this purpose because it would minimize the amount of control that would have to be introduced to remove secular phase drifts from the multiplier chain. These secular drifts would only be evident if two klystrons were stabilized through two multiplier chains to a single crystal reference source, and the relative phase of each klystron with respect to the other determined. Few applications would have such stringent stability requirements. On the other hand, there are advantages in having a simple multiplier chain, simply from the point of view of convenience.

Some investigation of single-stage multipliers is being carried out in the Microwave Spectroscopy Laboratory, M.I.T. In particular, it has been pointed out by Sharpless[5] that gallium arsenide shows no carrier storage effects for switching times of the order of 10^{-10} seconds. Gallium-arsenide crystals, kindly supplied by the Texas Instruments Company, are being investigated under operating conditions in which they are driven hard by a 10-mc potential into the conduction region and into the Zener breakdown region. At 10 mc, with 100-mw power at 10 mc into the crystal, we should be able to obtain 0.1 μw of power at 10,000 mc. This would be more power than is needed to obtain satisfactory low-noise phase-locking.

The author would like to acknowledge the assistance of J. G. Ingersoll in carrying out the phase-locking experiments reported here.

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[5] W. M. Sharpless, "High-frequency gallium arsenide point-contact rectifiers," *Bell Sys. Tech. J.*, vol. 38, pp. 259–269; January, 1959.

Beam Focusing by RF Electric Fields*

It is well known that the periodic electrostatic fields can focus electron beams. One might suppose that the RF electric fields with a distribution similar to those fields can focus the beam. We studied the case of a strip beam passing through a parallel plane waveguide which carries E_{01} mode, and obtained some general conclusions.

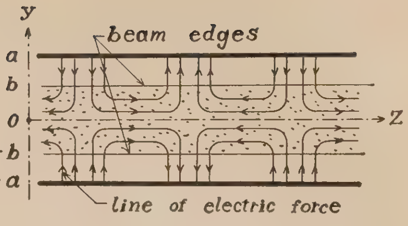

Fig. 1—Electric field distribution between two parallel planes.

Assumptions used are: 1) small perturbation, 2) the contribution of magnetic fields may be neglected, and 3) the term $(dy/dz)dv/dt$ may be neglected. The second assumption is reasonable if $u_0 \ll c$ and if the operating frequency is not near the cutoff points. Following the well-known procedure, one gets the path equation, eliminating t in the equation of motion.[1] The small perturbation from $y=b$ is expressed by

$$y_1 = q_1 \cos(\alpha z - \delta) + p_1 \sin(\alpha z - \delta),$$

$$\alpha = \frac{\omega}{u_0} + \beta, \qquad \delta = \frac{\omega}{u_0} z_0. \tag{1}$$

Substituting (1) into the path equation, one gets the condition of stability.[2]

It is of interest that the beam can not be focused by forward traveling waves. The power required to focus the beam by backward waves, P_1, is given by

$$P_1 = 8.02 \times 10^5 \frac{I_0}{F_1(\omega) \sin\left(\frac{b}{a}\pi\right)} \text{(watts/m)}$$

$$F_1(\omega) = \frac{(\omega_c/\omega)^2}{1 + \frac{u_0}{c}\sqrt{1-(\omega_c/\omega)^2}} \cdot \left[1 + \frac{u_0}{c}\left\{\frac{\sqrt{1-(\omega_c/\omega)^2}}{1 + \frac{u_0}{c}\sqrt{1-(\omega_c/\omega)^2}} - \frac{1}{\sqrt{1-(\omega_c/\omega)^2}}\right\}\right]. \tag{2}$$

The magnitude of perturbation q_1/b is of the order of $3\times10^{-2}\pm\sqrt{I_0 a}$. In the case of standing wave focusing, the necessary power P_2 (one-directional) is

$$P_2 = 1.01 \times 10^8 \frac{I_0/\sqrt{V_0}}{F_2(\omega)\sin\left(\frac{b}{a}\pi\right)} \text{(watts/m)}$$

$$F_2(\omega) = \left(\frac{\omega_c}{\omega}\right)^2 \frac{\{1-(\omega_c/\omega)^2\}^{3/2}}{1 - \left(\frac{u_0}{c}\right)^2\{1-(\omega_c/\omega)^2\}}. \tag{3}$$

q_2/b is of the order of $0.4\times\sqrt{I_0/\sqrt{V_0}}$. P_2 is larger than P_1 because the forward traveling waves have defocusing action. As the magnitudes of $F_1(\omega)$ and $F_2(\omega)$ are of the order of 1, P_1 and P_2 are considerably large for reasonable $I_0(A/m)$ (see Fig. 2). It is noted that P_1 is proportional to I_0, while P_2 to $I_0/\sqrt{V_0}$.

The explanation for defocusing action of forward traveling waves is as follows. The electric field of E_{01} mode is given by

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* Received by the IRE, October 26, 1959.

[1] P. K. Tien, "Focusing of a long cylindrical electron stream by means of periodic electrostatic fields," *J. Appl. Phys.*, vol. 25, pp. 1281–1288; October, 1954.

[2] Report presented to the Meeting of the Professional Group on Microwave Tubes of the IEE, Japan; July, 1959.

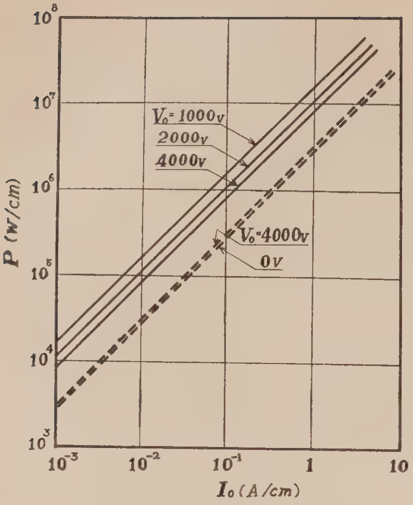

Fig. 2—Power required to focus the beam. Solid lines: power for standing waves. Dotted lines: power for backward traveling waves.

$$\begin{aligned} E_y &= \beta \sin k_y y \cos (\omega t \pm \beta z), \\ E_z &= \mp k_y \cos k_y y \sin (\omega t \pm \beta z). \end{aligned} \tag{4}$$

Putting $t=0$, (4) becomes

$$\begin{aligned} E_y &= \beta \sin k_y y \cos \beta z, \\ E_z &= - k_y \cos k_y y \sin \beta z. \end{aligned} \tag{5}$$

The field distributions of both forward and backward traveling waves are identical and similar to periodic electrostatic fields. To clarify the action of those traveling wave fields, it is helpful to see those fields from a moving coordinate that is traveling with a velocity equal to the mean velocity u_0 of electrons. Then $(\omega t \pm \beta z)$ is transformed into $(\omega/u_0 \pm \beta)z-(\omega/u_0)z_0$. The field distribution on the moving coordinates is obtained by substituting $\omega/u_0 \pm \beta$ into β of (5) and shifting the origin of coordinates. There are two cases: 1) $\omega/u_0 \pm \beta$ and β have the same sign or 2) they have the opposite sign. In the former case, the distribution is similar to periodic electrostatic fields. In the latter case, the phase relation between E_y and E_z is opposite to (5); electrons are axially decelerated when they experience outward force and accelerated when they experience inward force, which is contrary to the case of electrostatic lenses. In our E_{01} mode, the backward wave corresponds to the former case and the forward wave to the latter. This means the forward wave has defocusing action.

The phase relation between electric field components in slow wave circuit is the same as (5). In general, one may conclude that backward traveling waves and forward traveling waves which are slower than electrons can focus the beam, but forward traveling waves which are faster than electrons cannot.

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Determination of Sign of Power Flow in Electron Beam Waves*

The question very often arises of whether a particular electron beam wave carries positive power or negative power.[1] This can be particularly perplexing in dealing with transverse waves, because, associated with every transverse wave in an axially flowing electron beam, there are axial wave motions. The total power carried by the wave is, therefore, a combination of axial and transverse components, one of which may be positive and the other one negative. We propose here a method of determining the power flow for any wave, axial or transverse.

The best way to set up a "pure" electron wave of phase velocity v_1, is to couple the beam *loosely* to a circuit capable of carrying a pure wave at the same phase velocity; under this condition the circuit wave will slowly excite the beam wave. For typical electron beams, we need consider only quasi-static fields, where the phase velocity is so low that the electric fields of the wave differ negligibly from the fields of some electrostatic configuration moving at velocity v_1 with respect to a stationary observer. If we imagine ourselves moving at velocity v_1, we see purely static periodic fields. In such fields the radial velocity perturbations imparted (eventually) to the electrons must represent energy which is equal and opposite to the axial energy change experienced by the electrons. That is, as the electrons move through the static periodic fields and develop increasing radial velocities, they have the same increase in radial energy as decrease in axial energy. If, therefore, a radial velocity $\tilde{v}_r$ is imparted to the electrons, an axial velocity change $\tilde{v}_z$ is likewise imparted, in such a way that the total change in the ac energy or power in the beam is zero. The beam in the coordinate system of the wave is moving to the left at velocity (v_b-v_1), where v_b is the beam velocity in the laboratory coordinates. The energy relationship is

$$\tilde{v}_r^2 + (v_b - v_1 + \tilde{v}_z)^2 = (v_b - v_1)^2 \tag{1}$$

which reduces to

$$\tilde{v}_r^2 + 2\tilde{v}_z(v_b - v_1) + \tilde{v}_z^2 = 0;$$

for small signals,

$$\tilde{v}_r^2 = 2\tilde{v}_z(v_1 - v_b). \tag{2}$$

Now $\tilde{v}_z$ the axial velocity perturbation and $\tilde{v}_r$ the transverse velocity, are invariant with respect to the transformation from the moving coordinates to the laboratory system. Consequently, in laboratory coordinates, the total ac energy of the electrons is proportional to

$$W_{ac} = \tilde{v}_r^2 + (v_b + \tilde{v}_z)^2 - v_b^2 = \tilde{v}_r^2 + 2v_b\tilde{v}_z \tag{3}$$

(for small signals). Substituting from (2) we obtain

$$W_{ac} = \tilde{v}_r^2 + \tilde{v}_r^2 \frac{v_b}{v_1 - v_b} = \tilde{v}_r^2 \left(\frac{v_1}{v_1 - v_b}\right). \tag{4}$$

The "sign" of the ac power carried by the beam will be the same as the sign of W_{ac}. The relative proportion of axial and transverse power can also be obtained from (4). The factor $\tilde{v}_r^2$ is always positive so that the energy imparted to the electrons depends on the factor (v_1/v_1-v_b). From this factor, one can readily show that the condition for the wave to carry negative power is

$$v_b/v_1 > 1. \tag{5}$$

The phase velocities of space charge waves and cyclotron waves are given by

$$v_{1\ (\text{space charge})} = \frac{v_b}{1 \pm \dfrac{\omega_p}{\omega}},$$

$$v_{1\,(\text{cyclotron})} = \frac{v_b}{1 \pm \dfrac{\omega_c}{\omega}},$$

where in general, ω_p and ω_c have values depending on the beam geometry, as is well known. From (5), the slow space charge wave and the "slow" cyclotron wave both have negative power flow.

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* Received by the IRE, November 12, 1959.

[1] The "negative power" concept was first introduced by L. J. Chu. It is of great importance in gain and noise considerations.

Response of a Square Aperture to a Thermal Point Source of Radiation*

Antenna patterns are defined for point-source continuous wave targets. In these days of radio astronomy and thermal ground mapping, however, it is of interest to show the effective antenna pattern against a black body point source. It is evident from the start that an increase in bandwidth will receive more power, but produce some progressive pattern change from the familiar cw pattern.

Power radiated from a black body in the radio spectrum is given by the Rayleigh Jeans' approximation to Planks radiation formula.[1]

$$\frac{dP}{A_T d\lambda} = \frac{2\pi ckT}{\lambda^4} \quad \frac{\text{power}}{\text{unit area} \cdot \text{unit wavelength}} \tag{1}$$

where

A_T = projected area of source visible to antenna
λ = wavelength of radiation
k = Boltzmann's constant energy per degree of temperature
T = absolute temperature
c = velocity of light

An antenna is sensitive to only one polarization and thus can collect only half of this amount of power.

$$\frac{dP}{A_T d\lambda} = \pi ck \frac{T}{\lambda^4} = 1.3 \times 10^{-14} \frac{T}{\lambda^4} \frac{\text{watts}}{\text{meter}^3} \tag{2}$$

with λ expressed in meters, and T expressed in degrees Kelvin.

An antenna removed from the source a distance ρ and having an effective aperture

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* Received by the IRE, November 9, 1959.

[1] R. A. Smith, F. E. Jones, R. P. Chasmar, "The Detection and Measurement of Infrared Radiation," Oxford University Press, London, England, p. 27; 1957.

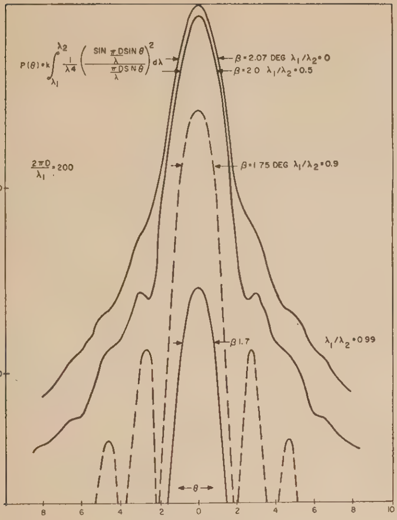

Fig. 1

of A_r receives power,

$$P = \frac{A_T \pi c k T}{4\pi\rho^2}\int_{\lambda_1}^{\lambda_2} \frac{A_r}{\lambda^4} d\lambda. \tag{3}$$

The effective area, A_r, is, in general, frequency-sensitive and depends upon the antenna design and target angle relative to the antenna. A square aperture uniformly illuminated would produce[2]

$$A_r(\theta\lambda) = A\left[\frac{\sin\left(\frac{\pi a}{\lambda}\sin\theta\right)}{\left(\frac{\pi a}{\lambda}\sin\theta\right)}\right]^2 \tag{4}$$

where the physical area $A = a^2$.

The reason for the selection of a square aperture is that this allows integration of (3) and just as ably demonstrates the effect as does a circular aperture which must be machine evaluated. Carrying this out, one finds

$$P = \frac{A_T c k T A\left[\sin\left(\frac{2\pi a}{\lambda_2}\sin\theta\right) - \frac{2\pi a}{\lambda_2}\sin\theta - \sin\left(\frac{2\pi a}{\lambda_1}\sin\theta\right) + \frac{2\pi a}{\lambda_1}\sin\theta\right]}{4\rho^{2}\tfrac{1}{2}[2\pi a\sin\theta]^3}. \tag{5}$$

Notice that in the limit at $\theta \to 0$ (target on the antenna axis)

$$P = \frac{A_T c k T A}{4\rho^2}\,\frac{1}{3}\left(\frac{1}{\lambda_1^3} - \frac{1}{\lambda_2^3}\right). \tag{6}$$

Using this as a normalization with $\lambda_2 = 0C$, the relative power pattern may be written

$$p = \frac{\sin\left(\frac{2\pi a}{\lambda_2}\sin\theta\right) - \frac{2\pi a}{\lambda_2}\sin\theta}{\frac{1}{6}\left(\frac{\lambda_2}{\lambda_1}\right)^3\left(\frac{2\pi a}{\lambda_2}\sin\theta\right)^3} - \frac{\sin\left(\frac{2\pi a}{\lambda_1}\sin\theta\right) - \frac{2\pi a}{\lambda_2}\sin\theta}{\frac{1}{6}\left(\frac{2\pi a}{\lambda_1}\sin\theta\right)^3}. \tag{7}$$

Eq. (7) is shown in Fig. 1 (on the left) for $\lambda_1/\lambda_2 = 0, 0.5, 0.9, 0.99$ or, to say this another way, for an infinite, octave, ten per cent, one per cent bandwidth. With increasing bandwidth the slightly increasing beamwidth and lowering of the sidelobe level should be noticed. Eventually, the lobes as such disappear. It is also of interest that for a given upper-frequency limit, once an octave bandwidth has been achieved only about 12 per cent more power is available by extending this to zero low frequency limit.

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[2] S. Silver, "Microwave Antenna Theory and Design," *Radiation Laboratory Series*, vol. 12, McGraw-Hill Book Co., Inc., New York, N. Y.

A Dispersionless Dielectric Quarter Wave Plate in Circular Waveguide*

Certain applications of circularly polarized waves at microwave frequencies require that the axial ratio of the wave approach unity (0 db) as closely as possible and maintain this value over a broad band of frequencies. Previous applications had permitted the use of quarter wave plates which generated circularly polarized waves having an axial ratio of as much as 3 db. This note describes an improved dielectric quarter wave plate for circular waveguide which generates a circularly polarized wave with an axial ratio under 0.2 db over the 12 per cent frequency band from 8.5 to 9.6 kmc.

It is well known that a circularly polarized wave can be generated by loading a waveguide of circular or square cross section with a slab of dielectric material in such a manner that equal-amplitude orthogonal waves experience a 90° differential phase shift upon passing through the loaded section of waveguide. The design of this type of a dispersionless differential phase shifter in square waveguide has yielded to rigorous analysis.[1-3] On the other hand designs for use in circular waveguide have been arrived at largely on an empirical basis because of the difficulty in obtaining exact solutions for the circular waveguide case.[1,4]

It is possible, however, to apply analytical techniques to the problem of dispersionless dielectric quarter wave plates if the parameters of desired differential phase shift, frequency limits and waveguide size are fixed and dominant mode propagation is assumed throughout. For these conditions, the solution obtained is specific rather than general and a design must be calculated for each set of parameters of interest. The method evolves from a consideration of the expression of the differential phase shift $\Delta\phi$ in a dielectric slab loaded waveguide

$$\Delta\phi = 2\pi l\left(\frac{1}{\lambda_p} - \frac{1}{\lambda_t}\right), \tag{1}$$

where λ_p is the guide wavelength existing in the waveguide when the slab is parallel to the plane of the E vector, and λ_t is the guide wavelength produced when the slab is transverse to the E vector. Using the definition for guide wavelength

$$\lambda_g = \frac{\lambda}{\sqrt{\epsilon - \left(\frac{\lambda}{\lambda_c}\right)^2}}, \tag{2}$$

(1) may be rewritten

$$\Delta\phi = \frac{2\pi l}{\lambda}\left[\sqrt{\epsilon_p - \left(\frac{\lambda}{\lambda_c}\right)^2} - \sqrt{\epsilon_t - \left(\frac{\lambda}{\lambda_c}\right)^2}\right], \tag{3}$$

where ϵ_p and ϵ_t are effective dielectric constants required to satisfy (2) for measured values of λ_p and λ_t. The effective dielectric constant will be smaller than the dielectric constant of the material employed since a waveguide partially filled with a dielectric material will have the same phase delay as a waveguide completely filled with a material of lower dielectric constant.

The dispersion D in a differential phase shift device may be defined as

$$D = \Delta\phi_1 - \Delta\phi_2, \tag{4}$$

where $\Delta\phi_1$ and $\Delta\phi_2$ are the differential phase shifts occurring, respectively, at f_1 and f_2, the frequency limits of interest. Assuming a given waveguide size and frequency band, and setting $\Delta\phi_1 = 90°$, the expression for dispersion about 90° differential phase shift becomes

$$D_{90^\circ} = \frac{\pi}{2}\left[1 - \frac{\lambda_1}{\lambda_2}\left(\frac{\sqrt{\epsilon_p - (\lambda_2/\lambda_c)^2} - \sqrt{\epsilon_t - (\lambda_2/\lambda_c)^2}}{\sqrt{\epsilon_p - (\lambda_1/\lambda_c)^2} - \sqrt{\epsilon_t - (\lambda_1/\lambda_c)^2}}\right)\right]. \tag{5}$$

Eqs. (3) and (5) were evaluated for the frequency band from 8500 to 9600 mc, assuming a 15/16-inch ID circular waveguide. In order to systematize the computation, ϵ_p and ϵ_t were chosen according to a regular progression of both the mean effective dielectric constant ϵ_m and the ratio of effective dielectric constants ρ where

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* Received by the IRE, October 19, 1959.

[1] W. P. Ayres, "Broadband Quarter Wave Plates," Electronic Defense Lab., Mountain View, Calif., Tech. Memo. No. EDL-M46; September 30, 1955.

[2] "Antenna Phenomena Research," Antenna Lab., Dept. of Electrical Engrg., Res. Foundation, Ohio State University, Columbus, Final Engrg. Rept. No. 594-7; November 1, 1955.

[3] H. S. Kirschbaum and S. Chen, "A Method of Producing Broadband Circular Polarization Employing an Anisotropic Dielectric," Antenna Lab., Dept. of Electrical Engrg., Res. Foundation, Ohio State University, Columbus, Engrg. Rept. No. 662-2; July 16, 1956.

[4] R. A. Brown and A. J. Simmons, "Dielectric Quarter Wave and Half Wave Plates In Circular Waveguide," Naval Res. Lab., Washington, D. C., Rept. No. 4218; November 10, 1953.

$$\epsilon_m = \sqrt{\epsilon_p \epsilon_t} \quad \text{and} \quad \rho = \frac{\epsilon_p}{\epsilon_t}. \tag{6}$$

The results of the computations are shown in Figs. 1(a) and 1(b). For the conditions chosen, the differential phase shift turns out to be solely a function of ρ and the dispersion is dependent only upon the value of ϵ_m. These curves, applied to the experimental measurements of ϵ_p and ϵ_t for various thicknesses of both polystyrene and teflon, resulted in plots of differential phase shift [Fig. 2(a)] and dispersion [Fig. 2(b)] as a function of dielectric slab thickness. Note that for the assumed case, minimum dispersion occurs in the region of high differential phase shift.

In designing a dispersionless quarter wave plate on the basis of these curves, consideration must, of course, be given to proper impedance matching. Only a stepped matching structure was considered in order to calculate the dispersion and differential phase shift occurring in the matching section. Using polystyrene of sufficient thickness to give a positive dispersion (3/16 inch in this case), steps were calculated to yield a binomial impedance change in the plane of the slab. Because of the thinness of the slab, it was hoped and borne out by subsequent measurements that no special matching measures would be required in the plane perpendicular to the slab. After calculating the differential phase shift introduced by the matching section, the length of the body of the quarter wave plate was computed to produce an over-all differential phase shift of 90°. Dispersion in the design was calculated to be about 1°.

Model quarter wave plates were constructed according to the calculated dimensions using both polystyrene and Rexolite, a material whose dielectric constant is the same as that of polystyrene. Axial ratios of between 0.2 and 0.3 db over the 12 per cent frequency band were obtained. Subsequent measurements indicated that the differential phase shift was slightly in excess of the desired 90°. By shortening the body of the dielectric element 0.015 inch, the error in the differential phase shift was reduced and a quarter wave plate which generates a circularly polarized wave of less the 0.2-db axial ratio was obtained. This is within 2 per cent of perfect circular polarization. The dimensions of the final model, designed to fit in 15/16-inch ID circular waveguide, are shown in Fig. 3, and the electrical performance characteristics of the unit are shown in Figs. 4(a) and 4(b).

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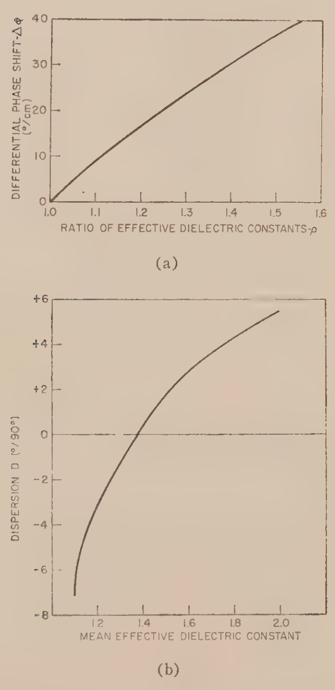
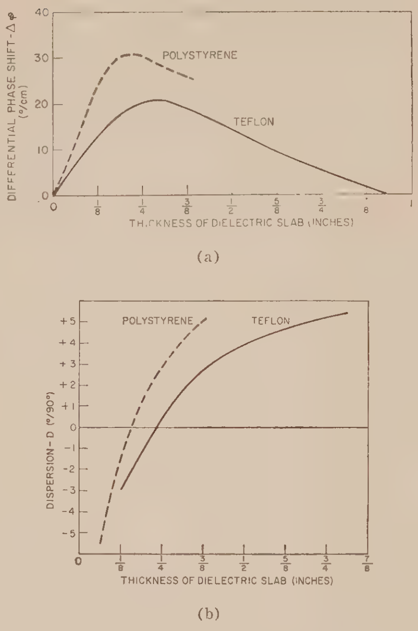


(a)

(b)

Fig. 1—(a) Differential phase shift vs ratio of effective dielectric constants for 15/16-inch ID circular waveguide at 8.5 kmc. (b) Dispersion about 90° vs mean effective dielectric constant for 15/16-inch ID circular waveguide in the frequency range 8.5 to 9.6 kmc.



(a)

(b)

Fig. 2—(a) Differential phase shift vs thickness of dielectric slab at 8.5 kmc. (b) Dispersion about 90° vs thickness of dielectric slab.

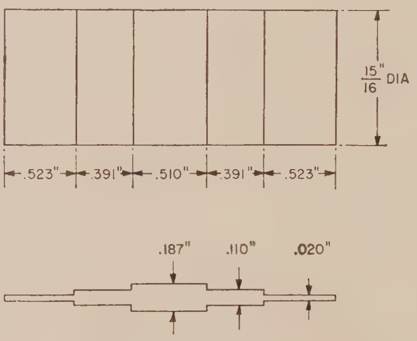
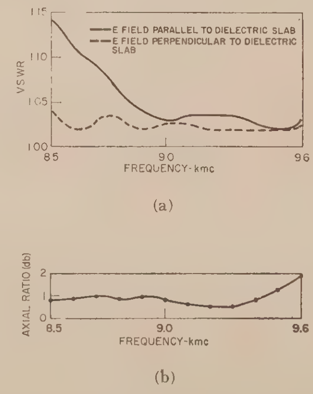


Fig. 3—A dispersionless quarter wave plate showing dimensions in inches. Material is polystyrene.



(a)

(b)

Fig. 4—(a) VSWR vs frequency for *E* field parallel and perpendicular to dielectric slab. (b) Output axial ratio of quarter wave plate.

Measuring the Mean Square Amplitude of Fading Signals Using a Selected Quantile Output Device (SQUOD)*

In many experiments it is necessary to measure the mean-square amplitude of a varying signal. The use of a square law detector is obvious. However, if the mean amplitude varies over a wide range, a system of attenuators has to be used, which is a disadvantage in automatic equipment designed to measure the signal over long periods.

The ideal receiver for measuring the amplitude of a signal which may vary over a wide range is one with a logarithmic characteristic such as that described by Chambers and Page.[1] The mean output from such a receiver does not, however, correspond to the root mean square signal. When the fading is completely random, for instance, the mean output is about 9 db in power below that corresponding to the rms signal.

The purpose of this note is to draw attention to the fact that, if the signal input to a nonlinear receiver consists of steady and random components as described by Rice,[2] then the quantile of the output voltages, chosen so that the receiver output is less than the quantile for 60 per cent of the time, is almost equal to the output corresponding to the rms-signal input. This is shown in Fig. 1 where the error in decibels, by which the input signals corresponding to the various quantiles exceed the rms-signal input, is plotted against the ratio of the square of the amplitude of the random component to the mean-square value of the signal, a measure of the depth of fading. It is seen that the quantile chosen leads to an error of less than 0.26 decibel, no matter what the depth of fading.

A device called a "Selected Quantile Output Device," or SQUOD, has been con-

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* Received by the IRE, December 1, 1959.

[1] T. H. Chambers and I. H. Page, "The high-accuracy logarithmic receiver," Proc. IRE, vol. 32, pp. 1307–1314; August, 1954.

[2] S. O. Rice, "Mathematical analysis of random noise," *Bell Sys. Tech. J.*, vol. 23, pp. 282–332, July, 1944; and vol. 24, pp. 46–156, January, 1945.

structed for determining the required quantile. The circuit, shown in Fig. 2, includes an amplitude comparator—the first ECC81—between the voltage input from the receiver and output to the recorder. The input voltage is a dc negative-going voltage varying from +20 to −20 volts. The adaption of the circuit to positive-going voltages is obvious.

The comparator operates a relay. With the relay closed or open, the condenser C (12 mf) charges or discharges through the resistance R, at uniform rates determined by the 15-volt or 22-volt batteries respectively, with R_2 (approximately 300 Ω) providing a fine control. The electrometer tube 4066 is used in a circuit basically due to Farmer.[3] The grid current is about 10^{-12} amp, allowing values of R up to about 10^{10} ohms. The voltage on the condenser C is thus transferred to the grid of the last half of the second ECC81, which acts as a cathode follower with a constant current load. As the battery voltages are fixed relative to the output voltage, the charging and discharging rates remain fixed.

The OA81 diode connected to the anode of the first ECC81 insures that, should the input voltage drop and the second half of the tube take all the current, the second anode cannot drop much below 85 volts and cannot force its grid to draw current.

The 4-mf condenser shunts the output of the electrometer tube and removes all ripple caused by fluctuating emission of the filament. This capacative shunt path is taken via the condenser C, in order to minimize phase lag in the control loop. As the electrometer tube has a gain of approximately one, the capacity seen in shunt with C from R is negligible.

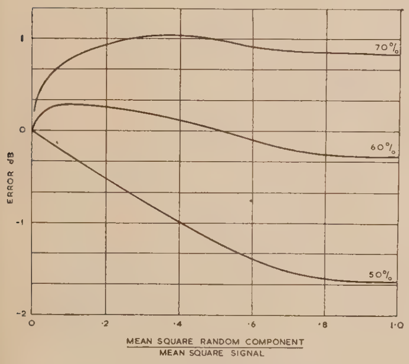

Fig. 1—The error in decibels by which the various quantile exceed the rms value, plotted against the ratio of the mean square value of the random component to the mean square value of the signal when the selected quantile exceeds the signal for 50, 60, and 70 per cent of the time.

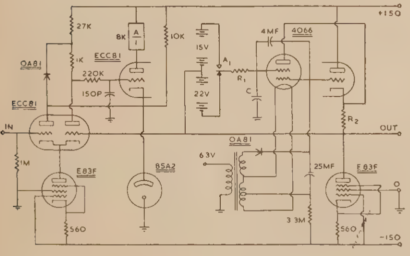

Fig. 2—Circuit of the SQUOD.

The device is sensitive to changes of input voltages of 0.05 volt, and has a working range of about 60 volts.

The SQUOD, in conjunction with the logarithmic receiver, is being used for automatic and accurate recording of the mean-square amplitude of echoes reflected from the ionosphere, and may be of use in other applications in which quantities to be measured are subject to random fluctuations.

The authors gratefully acknowledge the receipt of research grants from the University of New Zealand.

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[3] F. T. Farmer, "Electrometer for measurement of voltages on small ionization chambers," *Proc. Phys. Soc.*, vol. 54, pp. 435–438; September, 1942.

Observations on Angle Diversity*

Recently several papers have appeared discussing the use of angle diversity[1,2] in a tropospheric scatter system. These papers suggest that, at the upper UHF and SHF bands, angle diversity is much more efficient than any other type of diversity. It is the purpose of this note to attempt to clarify the characteristics of angle diversity, and to point out that it is probably no better than simple space diversity from S/N points of view and that the total real estate required is also the same. Angle diversity, however, will provide greater bandwidth capability because the very narrow beams utilized will cut down multipath delays.

To be specific, let us consider the analysis presented by Vogelman, *et al.*[2] They suggest the use of a very large antenna with multiple feeds at the transmitting end to illuminate the entire effective scatter volume with non-overlapping beams (measured by the 3 db points). By implication, each of the beams would illuminate only a fraction of that volume. Thus, if five feeds were used, each beam would illuminate approximately one-fifth of the effective scatter volume. Let us pursue the implication of this a little further by considering two cases. In each case, the total power output at the transmitter is the same. In one case, the power is split among the several feeds in a large antenna. In the other case, all the power is put into one smaller antenna whose beam fills the same volume as all the beams of the larger antenna do. Since the total power being fed in at the transmitting end is the same for both situations and the volume through which the power flows is also the same the power, density flux through the scatter volume must be the same for both cases. It would appear, therefore, that in general it would be preferable to put all the power into one feed of a smaller antenna than to use a complex arrangement of multiple feeds and multiple frequencies in a large antennas as has been suggested.[2] One qualification must be added. If the required total power output is many times the power output capability of a single tube, then the paralleling of many tubes at the transmitter may also become a difficult problem. However, to offset this difficulty, we have the following advantages: 1) paralleling several tubes is more efficient in terms of radiated power because the off-centering of the multiple feeds involves a loss of probably 3 to 6 db per feed; 2) the alignment of the larger beam associated with the smaller antenna becomes simpler; and (3) much less bandwidth is required.

Now let us consider the receiving end. If multiple feeds are placed in one large antenna, angle diversity could be achieved. However, the same S/N statistics can be achieved by the more conventional means of spaced smaller antennas and, moreover, the total real estate required would be the same for both cases. To make this clear, consider an antenna whose beamwidth just fills the effective scattering volume. In this discussion this antenna will be called the reference antenna. This antenna will realize its full free-space gain. Any larger antenna will suffer an antenna-to-medium coupling loss such that the received signal would be of comparable magnitude to the signal received on the reference antenna. Thus an antenna which has five times the area of the reference antenna will "see" approximately one-fifth of the effective scatter volume. A corollary to this is that phase coherence of the incoming wave is not maintained over the dimensions of this larger antenna. As a matter of fact, the phase of the incoming wave is coherent over an area approximately one-fifth that of the antenna itself. This means that we can place five smaller antennas, each the size of our reference antenna, in a diversity system in the same area occupied by the larger antenna, and as already stated, each of these smaller antennas will receive a signal of magnitude comparable to that received by the larger antenna. Thus, from this example we see that the one large antenna (five times the area of our reference antenna) which utilizes five different feeds arranged for diversity will give the same S/N statistics as five antennas each the size of our reference antenna. Also, the area occupied by either antenna system is the same. As mentioned at the beginning of this letter, the one advantage that a system utilizing a larger antenna with multiple feeds has is greater bandwidth capability. However, to achieve this angle diversity for the purpose of increasing bandwidth capability, one does not have to utilize multiple feeds and multiple frequencies in a large antenna at the transmitting end. One smaller antenna whose beam just fills the effective scatter volume will suffice.

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* Received by the IRE, November 2, 1959.

[1] R. Bolgiano, Jr., N. H. Bryant, and W. E. Gordon, "Diversity Research in Scatter Communications with Emphasis on Angle Diversity," Contract AF 30(602)-1717, Final Rept., pt. I; January, 1958.

[2] J. H. Vogelman, J. L. Ryerson, and M. H. Bickelhaupt, "Tropospheric scatter system using angle diversity," Proc. IRE, vol. 57, pp. 688–696; May, 1959.

Author's Comment[3]

Mr. Staras in his communication "Observations on Angle Diversity" has assumed that the purpose of this type of diversity is to illuminate the entire scatter volume with a uniform power density flux. I would like to point out that this is not the case. The purpose of angle diversity is to increase the reliability of tropospheric scatter communications. To this end, let me illustrate the advantages of angle diversity with numerical values rather than by pointing out flaws in Mr. Staras' letter.

Using Mr. Staras' illustration, let us compare the following two cases:

Case I. A 30-foot antenna with 4 units arranged for space diversity in the same geographic area as Case II; two antennas over two. Power per reflector is the same as power per feed in Case II. The frequency is 10 kmc.

Case II. A 60-foot antenna with 4 feeds in a row at 0° elevation. Power per feed is the same as power per reflector in Case I. The frequency is 10 kmc.

The distance between transmitter and receiver is 300 miles; Realized Gain[4] per antenna pair (1 receive and 1 transmit) for Case I is 86 db; and Realized Gain per beam pair (1 receive and 1 transmit) for Case II is 89.2, 89.9, 89.9, and 89.2, respectively. Using 50 per cent reliability for one path of Case I, identical transmitter power and receiver sensitivity, the reliabilities for the individual beams of Case II are 75 per cent, 80 per cent, 80 per cent and 75 per cent respectively.[5]

With quadruple space diversity, Case I gives an over-all reliability of 88 per cent or 120 errors per 1000, while 4 feed angle diversity gives in Case II an over-all reliability of 99.7 per cent or 3 errors per thousand.

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[3] Received by the IRE, December 4, 1959.

[4] L. P. Yeh, "Tropospheric Scatter System Design," Westinghouse Electric Corp., Baltimore, Md., Tech. Rept. No. 5; October, 1957. See Fig. 4.

[5] *Ibid.*, Fig. 6.

General N-Port Synthesis with Negative Resistors*

This note gives an n-port synthesis for any $n\times n$ admittance $[Y(p)]$, impedance $[Z(p)]$, or scattering $[S(p)]$, matrix, in which the matrix elements are general rational functions with real coefficients containing zeros and poles of arbitrary multiplicity anywhere in the complex frequency (p) plane. It will be shown that the synthesis can always be performed with passive elements (R, L, C, gyrators, ideal transformers) and negative resistors. This total group will here be defined as "physical elements."

First consider the synthesis of $Y(p)$. Express each element $y_{ij}(p)=\sum a_k p^k + y_{ij}^{(0)}(p)$ where $y_{ij}^{(0)}(p)$ is a proper fraction and hence has no poles at ∞. Then $Y(p) =\sum p^k A_k + Y_0(p)$, where the A_k are real constant matrices. Let us consider the synthesis of one of the matrices p^kA_k. A_k may be separated into its symmetric (A_k'') and skew symmetric (A_k') parts, and each of these diagonalized by a real congruent transformation. The symmetric part p^kA_k'' goes into diag $(p^k, p^k, \cdots, 0_{r+1}, \cdots, 0_n)$ where the rank of A_k'' is r. The skew symmetric part, $p^k A^{k'}$, goes into

$$\text{diag}\cdot\begin{bmatrix}0 & p^{-k}\\ p^k & 0\end{bmatrix},\begin{bmatrix}0 & -p^k\\ p^k & 0\end{bmatrix},\ 0_{m+1},\cdots 0_n$$

where the rank of A_k' is m, an even number. Each 0_j is a scalar zero. We have then merely to show the synthesis of the diagonal elements

$$\pm p^k,\ \begin{bmatrix}0 & -p^k\\ p^k & 0\end{bmatrix},$$

and by appropriate transformers and parallel interconnections[1] $\sum p^kA_k$ may be synthesized as an n-port.

Fig. 1 shows how the admittance element $\pm p^2$ is synthesized; and in conjunction with the negative impedance converter circuit of Fig. 2, it is clear that $\pm p^2$ only requires passive elements and negative resistors. Fig. 3 shows how the admittance $\pm p^{n+1}$ can be synthesized in terms of elements of lower degree. Hence, by induction any p^k may be constructed of physical elements. Fig. 4 shows the realization of the admittance matrix

$$\begin{bmatrix}0 & -p^k\\ p^k & 0\end{bmatrix}$$

in terms of physical elements, where the admittance element $\pm p^k$, synthesized above, is used as a building block.

The next step is to synthesize $Y_0(p)$, whose singularities are all in the finite p plane. Let σ_0 be the positive real part of that pole of $Y_0(p)$ located farthest to the right of $j\omega$ in the complex p plane. Then make the frequency transformation $s=p-\tau$, $\tau>\sigma_0$. The function $Y_0(s)$ is now analytic on $j\omega$ and in the right half p plane, though it need not be passive (*i.e.*, it need not possess a positive quadratic form for internally dissipated power). The synthesis of such a $Y(s)$ has been given previously as a passive network some of whose ports are augmented by series-connected negative resistors.[1] Each coil L in the network for $Y_0(s)$ is now replaced by the series combination of L and a negative resistor $-L\tau$, and each condenser C by C in parallel with negative conductance $-C\tau$. This gives $Y_0(p)$ as a network with physical elements, and the parallel combination of $Y_0(p)$ with $\sum p^kA_k$ completes the synthesis.

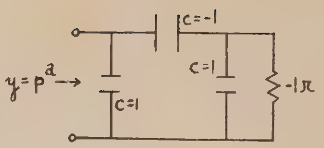

Fig. 1.

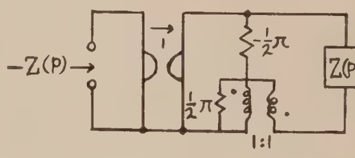

Fig. 2.

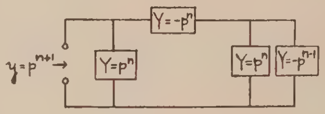

Fig. 3.

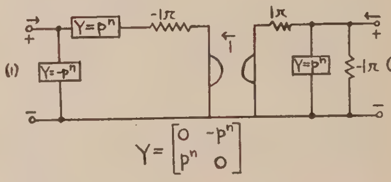

Fig. 4.

It is clear that $Z(p)$ may be synthesized by a dual process.

Suppose now that $S(p)$ is specified, and neither the $Z(p)$ nor $Y(p)$ representations corresponding to this S exists. Since S exists, the admittance matrix Y_A of an augmented network exists,[2] corresponding to the network for $S(p)$ with a unit positive resistor added in series to each port. $Y_A=\frac{1}{2}(I-S)$. $Y_A(p)$ is synthesized as described above to give the augmented network N_A. To find N corresponding to S, we "de-augment" N_A by adding -1 ohm resistors to each port of N_A No attempt has been made to minimize the number of elements, but the synthesis given proves the general theorem:

Any $n\times n$ scattering matrix of rational real functions of p can be represented by a linear, time invariant, lumped n-port network containing only passive elements and negative resistors.

The number of resistors can be reduced by the following technique. Consider $Y(p)$ and suppose all boundary poles have been removed, so that $Y(j\omega)$ is bounded. Simple poles on $p=j\omega$ with positive residue matrices are removable as passive lossless networks, and higher-order boundary poles as well as simple boundary poles with non-positive residue matrices are synthesized by a simple modification of the technique given above in connection with Figs. 1–4. Write $Y(p) = Y_1(p)+Y_2(p)$, where, by combining appropriate terms of a partial fractions expan-

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* Received by the IRE, November 20, 1959. This work was done under Contract AF-18(600)-1505 sponsored by the Army, Navy and Air Force.,

[1] H. J. Carlin, "The synthesis of non-reciprocal networks," *Proc. Symp. on Modern Network Synthesis II*, Polytechnic Institute of Brooklyn, Brooklyn, N. Y., vol. 5, pp. 11–44; April, 1955.

[2] H. J. Carlin, "The scattering matrix in network theory," IRE TRANS. ON CIRCUIT THEORY, vol. CT-3, pp. 88–97; June, 1956.

sion, $Y_1(p)$ has only left-half p-plane poles and $Y_2(p)$ has only right-half p-plane poles. Now $Y(p)=\hat{Y}_1(p)+\hat{Y}_2(p)$, where $\hat{Y}_1(p)=G+Y_1(p)$, $\hat{Y}_2(p)=-G+Y_2(p)$. $G=\text{diag}(g_1, g_2, \cdots, g_n)$ where the g_k are all real, non-negative, and may be chosen equal to each other, with g_k the maximum value required to make $\hat{Y}_1(p)$ and $-\hat{Y}_2(-p)$ positive real matrices. This can always be done with a real finite g_k since $Y(j\omega)$ is bounded, and $\hat{Y}_1(p)$ and $-\hat{Y}_2(-p)=G-Y_2(-p)$ are both analytic in the right half of the p plane.[1] The positive real matrix $\hat{Y}_1(p)$ may always be synthesized as a passive network containing at most n resistors all positive. By a theorem of Youla,[3] if $-\hat{Y}_2(-p)$ is PR, then $\hat{Y}_2(p)$ may be synthesized as a network containing lossless elements plus at most n resistors, all negative. Combining $\hat{Y}_1(p)$ and $\hat{Y}_2(p)$ in parallel gives $Y(p)$. Utilizing duality, we may state the following general theorem.

Any $n\times n$ immittance matrix of rational functions, which has no boundary ($p=j\omega$) poles other than those of simple order with non-negative residue matrices at these boundary poles, may be synthesized as an n-port network containing only lossless elements and at most n-positive and n-negative resistors.

A driving point impedance of the above type, for example, requires at most one positive resistor and one negative resistor.

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[3] Microwave Res. Inst., Polytechnic Institute of Brooklyn, Brooklyn, N. Y., MRI Quarterly Rept. No. 16, R-452.16-59, pp. 55–56; April 15, 1959. Contract No. AF-18(600)-1505.

A Signal Flow Graph Method for Determining Ladder Network Functions*

An iterative method for determining ladder network functions was described by Kuo and Leichner,[1] with the suggestion that the signal flow method was not very convenient. For comparison, a signal flow solution is presented here.

Using the same circuit as Kuo and Leichner, a ladder with series impedances $Z_1(s)$ and $Z_3(s)$ and shunt admittances $Y_2(s)$ and $Y_4(s)$, and the same equations written in their simplest forms,

$$V_2(s) = V_2(s), \tag{1}$$

$$I_2(s) = Y_4(s)V_2(s), \tag{2}$$

$$V_a(s) = I_2(s)Z_3(s) + V_2(s), \tag{3}$$

$$I_1(s) = Y_2(s)V_a(s) + I_2(s), \tag{4}$$

$$V_1(s) = I_1(s)Z_1(s) + V_a(s), \tag{5}$$

a signal flow graph may be drawn (Fig. 1).

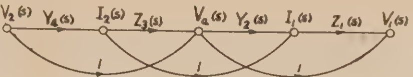

Fig. 1—A signal flow graph method for determining ladder network functions.

There are no feedback paths, so the determinant has a value of unity. The following relations may then be written by inspection[2] (if it is remembered that any node may be treated as a sink).

$$\frac{V_1(s)}{V_2(s)} = Y_4(s)Z_3(s)Y_2(s)Z_1(s) + Y_4(s)Z_3(s) + Y_4(s)Z_1(s) + Y_2(s)Z_1(s) + 1, \tag{6}$$

$$\frac{I_1(s)}{V_2(s)} = Y_4(s)Z_3(s)Y_2(s) + Y_4(s) + Y_2(s), \tag{7}$$

$$\frac{I_1(s)}{V_2(s)} = Y_4(s). \tag{8}$$

From these,

$Z_{\text{in}}(s) = V_1(s)/I_1(s)$ = (6) divided by (7);

$I_2(s)/I_1(s)$ = (8) divided by (7);

$V_2(s)/V_1(s)$ = the reciprocal of (6);

$Z_{21}(s) = V_2(s)/I_1(s)$ = the reciprocal of (7).

Thus, all the network functions may be obtained by inspection of one graph.

The form of the result is slightly different from that given by Kuo and Leichner, and the relative convenience or shortness of the methods may depend on the particular problem, and on the types of immittance involved.

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* Received by the IRE, November 2, 1959.

[1] F. F. Kuo and G. H. Leichner, "An iterative method for determining ladder network functions," Proc. IRE, vol. 47, pp. 1783–1784; October, 1959.

[2] S. J. Mason, "Feedback theory—further properties of signal flow graphs," Proc. IRE, vol. 44, pp. 920–926, July, 1956.

A Different Approach to the Approximation Problem*

The response curves that are usually desired in network theory cannot be exactly synthesized. A reasonable approximation to the desired response is therefore made and the corresponding network is synthesized. Where an infinite number of "reasonable approximations" exist, there are an infinite number of solutions to the problem.

It is possible to follow a less arbitrary approach, based upon the fact that a physically realizable response curve can be expressed as an exact function of s, where $s=j\omega$. Consider the amplitude and phase responses of curves A to D in Fig. 1, where ω_0 is a nominal cutoff frequency.

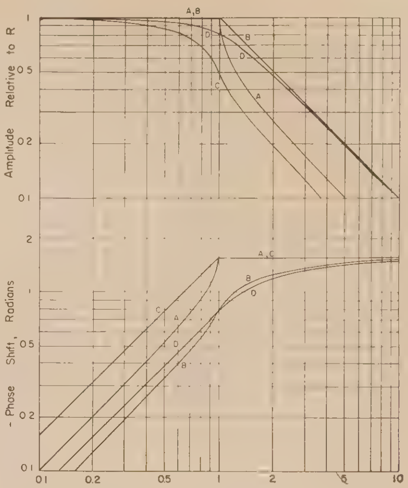

Fig. 1—Various "ideal" response curves.

For curve A, the amplitude response is flat up to ω_0 while the phase response is flat beyond ω_0. It is described by[1]

$$Z = \frac{R}{\dfrac{s}{\omega_0} + \sqrt{1 + \left(\dfrac{s}{\omega_0}\right)^2}}\,. \tag{1}$$

For curve B, the amplitude response is flat up to ω_0 and decreases at a 6 db/octave rate beyond ω_0. It is given by[1]

$$Z = \frac{R}{\exp\left(\dfrac{2}{\pi}\displaystyle\int_0^{s/\omega_0} \frac{\text{arc tan } x}{x}\, dx\right)}\,. \tag{2}$$

For curve C, the phase response is linear up to ω_0 and remains at $-\pi/2$ radians beyond ω_0. Here we have[2]

$$Z = \frac{R}{\sqrt{1 + \left(\dfrac{s}{\omega_0}\right)^2} \exp\left(\dfrac{s}{\omega_0} \text{ arc tan } \dfrac{\omega_0}{s}\right)}\,. \tag{3}$$

For curve D, the phase response is linear up to ω_0, reaching $-\pi/4$ radians, and increases to $-\pi/2$ radians beyond ω_0. Here,[2]

$$Z = \frac{R\sqrt{\epsilon}}{\sqrt{1 + \left(\dfrac{s}{\omega_0}\right)^2} \exp\left[\dfrac{1}{2}\left(\dfrac{s}{\omega_0} \text{ arc tan } \dfrac{\omega_0}{s} + \dfrac{\omega_0}{s} \text{ arc tan } \dfrac{s}{\omega_0}\right)\right]}\,. \tag{4}$$

As an application of curves A and B, consider a numerical problem involving a Bode step transition.[1] The system is shown in Fig. 2. Unity transconductance amplifiers are assumed. Three of the interstage networks, Z_{RC}, consist of a 1-farad capacitor in parallel with a 1-ohm resistor. The fourth network, Z_S, is to be synthesized so as to

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* Received by the IRE, October 27, 1959. This work was supported in part by the Office of Naval Research under Contract Nonr-839(05).

[1] S. Deutsch, "Synthesis of Infinite Zero-Pole Network Structures," Microwave Res. Inst., Polytechnic Inst. of Brooklyn, N. Y., R-739-59; May, 1959.

[2] S. Deutsch, "A General Class of Maximally-Flat Time Delay Response Ladders," Microwave Res. Inst., Polytechnic Inst. of Brooklyn, N. Y., R-773-59; September, 1959.

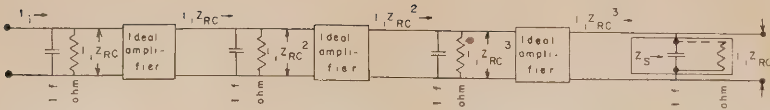

Fig. 2—The system assumed for the step transition of Fig. 3.

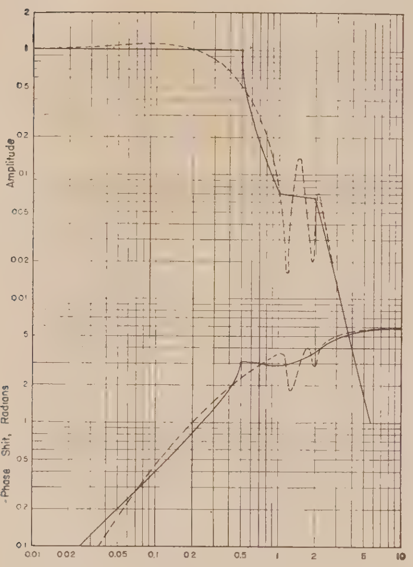

Fig. 3—Amplitude and phase responses of the step transition transfer impedance.

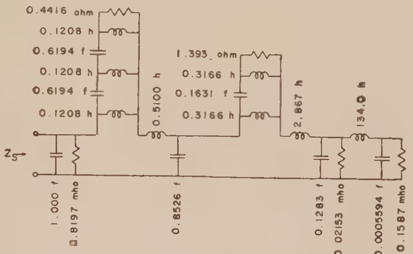

Fig. 4—The shaping network approximation for Fig. 3.

achieve a given system transfer impedance, Z_{TR}. The various impedances are related by $Z_{TR}=Z_{RC}{}^3 Z_S$. Two restrictions are imposed on Z_S: the first shunt element must be a 1-farad capacitor, and Z_S must approach 1 ohm as s approaches zero.

The given amplitude and phase responses of Z_{TR} are shown as the solid curves in Fig. 3. From (1) and (2), we can express Z_{TR} analytically as

$$Z_{TR} = \left[\frac{s}{0.5} + \sqrt{1+\left(\frac{s}{0.5}\right)^2}\,\right]^{-2}$$

$$\cdot\left[\exp\left(\frac{2}{\pi}\int_0^s \frac{\text{arc tan } x}{x}\,dx\right)\right]^2$$

$$\cdot\left[\exp\left(\frac{2}{\pi}\int_0^{s/2} \frac{\text{arc tan } x}{x}\,dx\right)\right]^{-4}. \quad (5)$$

Since $Z_{RC}=1/(s+1)$, the Z_S driving-point impedance is given by

$$Z_S = Z_{TR}(s+1)^3. \quad (6)$$

When (5) and (6) are combined, the following series expansion is obtained:

$$\frac{1}{Z_S} = s + 0.8197 + \frac{1.961}{s} - \frac{1.698}{s^2} + \frac{0.06414}{s^3}$$

$$- \frac{1.674}{s^4} + \frac{5.706}{s^5} - \frac{3.960}{s^6} - \frac{2.820}{s^7}$$

$$- \frac{3.388}{s^8} + \frac{22.93}{s^9} - \frac{10.27}{s^{10}} - \frac{40.41}{s^{11}}$$

$$+ \cdots. \quad (7)$$

Since (7) is an infinite series, it can be realized only with an infinite number of elements. Fig. 4 shows the corresponding network approximation with 20 elements. The dotted curves in Fig. 3 show the Z_{TR} responses when the network of Fig. 4 is employed. One can approach the desired response to any degree of accuracy by carrying (7) out to additional terms and synthesizing additional elements in the network of Fig. 4.

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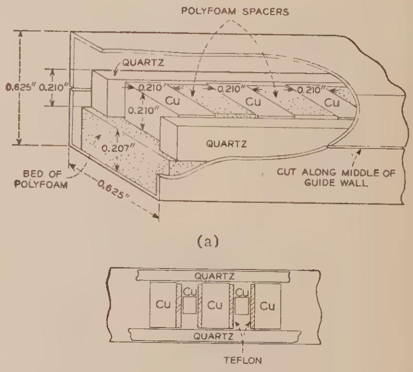
The Block Loaded Guide as a Slow Wave Structure*

Fig. 1 shows a square cross-section wave guide cut into two U-shaped parts along the center line of two opposite walls, and loaded with small copper blocks and dielectric. The blocks rest on a bed of polyfoam and lie in a line along the center of the guide. They occupy a region which, in the TE_{10} modes of the empty guide, would contain the maximum electric field. Thus, they constitute a capacitative load, which is still further increased by the strips of dielectric filling the space between them and the guide wall. Individually, the blocks are resonators with fundamental frequencies below the cutoff frequency of the guide; together they form a coupled chain, and act as a slow wave circuit.

The field configuration of the slow wave resembles that of the corresponding TE_{10} wave and is sketched in Fig. 2(b). The group velocity is controlled by the size of the gaps between blocks and side walls, by the nature of the dielectric, and by the spacing between blocks. The first two factors together constitute a loading capacity, and slow the wave in much the same manner as dielectric loading alone. The block spacing determines coupling between resonators, and can be made to give any arbitrary degree of slowing at the cost of a narrower bandwidth. A third mode of propagation, sketched in Fig. 2(d), may be compared with the TM_{11} mode of the empty guide, or with the mode of propagation along a coaxial line. In contrast with the latter, it has a low frequency cutoff, determined principally by the distance between blocks. The cutoff may be lowered by using a dielectric material to separate the blocks, or by placing smaller copper blocks between the large ones, as shown in Fig. 1(b). Both of these are methods of increasing the block to block capacity. In the notation used here, I and II are the slow wave modes analogous to the TE_{10} mode, and III is the mode analogous to the TM_{11} mode. Only one of the slow modes (I) was studied in the model. The other (II) was not provided with any dielectric loading, and was heavily damped by the cut along the guide wall. The magnetic fields of I and II have a component parallel to the length of the guide, and the field of III is mainly transverse.

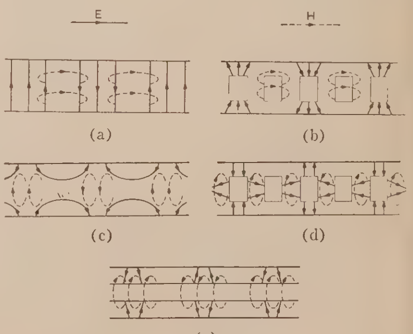
The dimensions of the test structure are shown in Fig. 1 and correspond to cutoff frequencies in the empty guide of 9.5 kmc for the TE_{10} mode and 13.4 kmc for the TM_{11} mode. Three sizes of block were used—in the first two cases with a quartz dielectric, and in the last case with a stack of mica strips



(a)

(b)

Fig. 1.



(a) (b)

(c) (d)

(e)

Fig. 2.

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* Received by the IRE, November 25, 1959.

TABLE I

Block size	Capacity gap	Interblock spacing	Slowing factor	Mid-range frequency
0.210 inch ×0.210 inch ×0.360 inch	42 per cent	0.210 inch 0.420 inch 0.630 inch	4.6 7.0 14	5.5 kmc
0.210 inch ×0.210 inch ×0.470 inch	25 per cent	0.210 inch 0.420 inch 0.630 inch	6.3 9.5 20	4.5 kmc
0.210 inch ×0.210 inch ×0.560 inch	10 per cent	0.210 inch 0.420 inch	10 17	3.0 kmc

between the line of blocks and the side walls. Signals were coupled in and out by loops which could be rotated to make tests of the magnetic field direction. Loaded with n blocks, and lightly coupled to a power source and detector, the structure formed a multiply resonant system with n mode I resonances below the cutoff frequencies of the empty guide. In the ideal case, these give points on the dispersion curve of an infinite line;[1] in the model, there were unavoidable end effects, but tests performed, by adding a block at a time and repeating measurements, showed that five or six blocks gave a reasonable approximation. Slowing factors (free space velocity÷group velocity) were estimated by taking the gradient of the dispersion curve at its mid point, *i.e.*, where the blocks form $\frac{1}{4}\lambda$ sections, and where the slowing factor has a stationary minimum value. In most tests, polyfoam spacers were used between neighboring blocks, but some tests were also made with quartz spacers and with the block and teflon arrangement of Fig. 1(b). The principal effect of this change was to increase the block-to-block capacity and to bring mode III down into the mode-I range (where the two types of resonance could be distinguished by rotating the coupling loops). Mode I was hardly affected by altering the block-to-block capacity, although a small reduction in the slowing factor was noted with the Fig. 1(b) arrangement, probably because of additional electrostatic coupling between the resonating sections.

Some slowing factors for different block sizes and spacings are shown in Table I, The mid-range frequencies vary slightly with interblock spacing, and the values given are only approximate. "Capacity gap" denotes twice the distance between a block face and the side wall, expressed as a percentage of the total wall-to-wall distance. Blocks were spaced from the side walls with quartz or mica, and from one another with polyfoam.

At many of the resonances, Q-values in excess of 1000, corresponding to a loss of under $\frac{1}{2}$ db per meter at a slowing factor of 20, were obtained. This low loss is probably explained by the absence of metal-to-metal joins in the structure. It should be possible to obtain larger slowing factors by substituting strips of Al_2O_3 ceramic ($k\sim 10$) or TiO_2 ceramic ($k\sim 80$) for the quartz.

In general, the block and dielectric loaded guide is distinguished by low loss, versatility of design, and ease of construction; and it should be particularly appropriate where strong coupling with the magnetic, rather than with the electric, field is required. It may be noted that, in the test model, the region of strong electric field was filled with material, but the region of strong magnetic field (altogether $\frac{2}{3}$ of the volume) was free. As a traveling-wave maser structure it would have some special advantages. With mode I as the signal and mode III as the pump, the two H fields would be mutually perpendicular, and would overlap in the empty spaces above and below the block and dielectric strip. An external dc field applied at right angles to the length of the guide would be perpendicular to the signal field, and could have various orientations with respect to the pump. The characteristics of modes I and III can be determined with a certain amount of mutual independence, and mode III can be set beyond the mode I range, so that no fraction of the signal is coupled into the incorrect mode. Capacitative loading slows the wave, without a corresponding narrowing of the pass band. It reduces the cross section as well as the length of the structure, thus simplifying the problem of mounting in a strong magnetic field at low temperatures, and also making it possible to obtain a good filling factor, with economy in the amount of paramagnetic material and in the pumping power needed to keep it continually activated.

W. B. Mims
Bell Telephone Labs., Inc.
Murray Hill, N. J.

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[1] D. A. Watkins, "Topics in Electromagnetic Theory," John Wiley and Sons, Inc., New York, N. Y., pp. 9–10; 1958.

Reduction of Sidelobe Level and Beamwidth for Receiving Antennas*

In the conventional application of the Dolph-Tchebycheff technique[1] an array of $N+1$, isotropic, in-phase radiators, spaced $\lambda/2$ apart, yields an optimized relationship between the beamwidth and sidelobe level of the antenna pattern, provided the method of combining the signals from the individual elements is the usual simple one. The weighting coefficient for each element is determined by the correspondence required between the antenna pattern $T_N(u)$ (where $u=\sin\theta$ and θ is measured from broadside), and the Tchebycheff polynomial, $T_N(x)$, of degree N.

It will be shown that if a slightly more complicated system behind the antenna is used, then an antenna pattern corresponding to T_{2N} may be obtained *on receive*. Fundamentally, the method consists of utilizing the identity:[2]

$$\frac{1}{2}T_{2N}(x) = \left(T_N(x)+\frac{1}{\sqrt{2}}\right)\left(T_N(x)-\frac{1}{\sqrt{2}}\right). \qquad (1)$$

Certain features of this new technique are similar to those used in a scheme[3] for improving two-way patterns.

Fig. 1 shows a schematic drawing for the case of a nineteen-element array. The term $e_1(u, t)$ denotes the RF signal which results when signals are combined from the individual elements in the conventional Dolph-Tchebycheff manner. In addition, the center element is tapped so as to yield two equal RF signals, e_2 and e_3. The three channels are then combined as shown in Fig. 1. The complete expression for the voltage in each branch of the device is given in Table I.

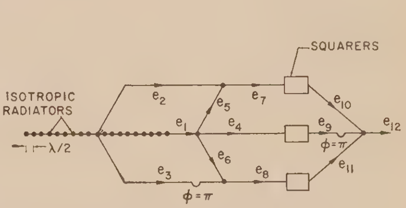

Fig. 1—Diagram illustrating new technique for reduction of sidelobe level and beamwidth for receiving antennas.

TABLE I
VOLTAGE IN EACH BRANCH OF ANTENNA SHOWN IN FIG. 1

$$e_1(u,t) = \sqrt{6}\,T_{18}(u)\cos\omega t$$
$$e_2(u,t) = (1/\sqrt{2})\cos\omega t$$
$$e_3(u,t) = (1/\sqrt{2})\cos\omega t$$
$$e_4(u,t) = 2T_{18}(u)\cos\omega t$$
$$e_5(u,t) = T_{18}(u)\cos\omega t$$
$$e_6(u,t) = T_{18}(u)\cos\omega t$$
$$e_7(u,t) \equiv e_5+e_2 = (T_{18}(u)+1/\sqrt{2})\cos\omega t$$
$$e_8(u,t) \equiv e_6-e_3 = (T_{18}(u)-1/\sqrt{2})\cos\omega t$$
$$e_9(u,t) = 4T_{18}{}^2(u)\cos^2\omega t = 2T_{18}{}^2(u)(\cos 2\omega t+1)$$
$$e_{10}(u,t) = (T_{18}(u)+1/\sqrt{2})^2\cos^2\omega t = (1/2)(T_{18}{}^2(u) + \sqrt{2}\,T_{18}(u)+1/2)(\cos 2\omega t+1)$$
$$e_{11}(u,t) = (T_{18}(u)-1/\sqrt{2})^2\cos^2\omega t = (1/2)(T_{18}{}^2(u) - \sqrt{2}\,T_{18}(u)+1/2)(\cos 2\omega t+1)$$
$$e_{12}(u,t) = e_{10}+e_{11}-e_9 = (T_{18}{}^2-1/2)(\cos 2\omega t+1) = (1/2)T_{36}\cos 2\omega t+(1/2)T_{36}$$

The output $e_{12}(u, t)$ thus corresponds to a Tchebycheff polynomial of degree 36. In principle either the time-varying or the direct current component of e_{12} may be detected.

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* Received by the IRE, November 20, 1959.

[1] C. L. Dolph, "A current distribution for broadside arrays which optimizes the relationship between beam width and side lobe level," PROC. IRE, vol. 34, pp. 345–348; June, 1946.

[2] "Tables of Chebyschev Polynomials $S_n(x)$ and $C_n(x)$," NBS Appl. Math. Ser. 9, U. S. Govt. Printing Office, Washington, D. C.; December, 1952.

[3] R. L. Mattingly, Bell Telephone Labs., Private Communication; July, 1959.

Characteristics of this antenna are compared to those of several conventional arrays in Table II. Because of the lack of a unique basis for comparison of this new technique and the conventional Dolph-Tchebycheff technique, the cases below were computed. The results of the application of this new technique are listed in row one.

TABLE II
PATTERN CHARACTERISTICS

Case No.	Signal Combination Method	No. of Elements	Full Beamwidth	Sidelobe Level
1	New technique	19	10.7°	−19 db
2	Conventional	19	12.0°	−16 db
3	Conventional	19	13.3°	−19 db
4	Conventional	19	10.7°	−12.5 db

If it is required that the new and conventional techniques yield the same beamwidth, then comparison of cases 1 and 4 shows that the new technique yields sidelobes which, theoretically, are better by 6½ db. If the sidelobe level is the primary consideration, then cases 1 and 3 show that the new technique yields a full beamwidth which is better by 2.6°. The set of weighting coefficients for cases 1 and 2 are equal except for the center element. In this last comparison the new technique yields an improvement in full beamwidth of 1.3° and the sidelobe level is improved by 3 db.

These improvements of the conventional Dolph-Tchebycheff pattern are effected at the cost of decreasing the effective one-way range by about 25 per cent. In applications where power is abundant and high discrimination is desired, this new technique could be cascaded with still further improvements in the pattern. For example, the next step in the cascade would make use of the identity:

$$\frac{1}{2} T_{4N} = 4\left[\left(T_N+\frac{1}{\sqrt{2}}\right)\left(T_N-\frac{1}{\sqrt{2}}\right)+\frac{1}{\sqrt{8}}\right]\cdot\left[\left(T_N+\frac{1}{\sqrt{2}}\right)\left(T_N-\frac{1}{\sqrt{2}}\right)-\frac{1}{\sqrt{8}}\right]. \quad (2)$$

A new technique which improves the conventional Dolph-Tchebycheff antenna pattern has been presented. It has been shown that the beamwidth and the sidelobe level may be reduced at the cost of increasing the complexity of the components behind the antenna and by allowing a decrease in the effective range.

The new technique is applicable only for receiving antennas. The nonreciprocity is due to the use of nonlinear detectors as an integral part of the scheme.

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Contributors

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Edward W. Allen (M'44–F'53) was born in Portsmouth, Va., on February 14, 1903. He received the E.E. degree from the University of Virginia, Charlottesville, in 1925, and the L.L.B. degree from George Washington University, Washington, D. C., in 1933.

Joining the Federal Communications Commission in 1935, he became chief of its Technical Research Division in 1946. Since 1951, he has been Chief Engineer of the FCC; and, throughout his association with the Agency, he has been active in the development of technical standards and radio allocations. A member of the Electrical Standards Board of the American Standards Association, he has participated in electrical coordination work for many years.

Mr. Allen is also a member of the national committees of URSI and of the International Electrotechnical Union.

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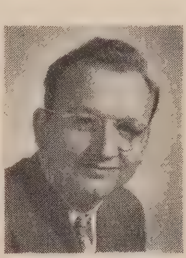

W. L. BEHREND

W. L. Behrend (M'48–SM'53) was born on January 11, 1923, in Wisconsin Rapids, Wis. He received the B.S. and M.S. degrees in 1946 and 1947, respectively, both from the University of Wisconsin, Madison.

From 1944 to 1946, he served as an electronic technician in the U. S. Navy. In 1947, he joined the RCA Laboratories Division, Princeton, N. J., where he is now with the Systems Research Laboratory. He has been associated with the development of antennas, experimental UHF television transmitter, and color television.

Mr. Behrend is a member of Sigma Xi.

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R. M. BOWIE

Robert M. Bowie (A'34–M'37–SM'43–F'48) was born in Table Rock, Neb., on August 24, 1906. He received the B.S. degree in chemistry, and the M.S. and Ph.D. degrees in physics in 1929, 1931, and 1933, respectively from Iowa State University, Ames.

In 1933, he joined the engineering staff of Hygrade Sylvania Corporation, Emporium, Pa., to do physical research on radio tubes. In 1934, he began the establishment of a physical research laboratory, and in 1935, the laboratory was expanded with principal emphasis on television tube research. In 1939, this laboratory was split into two parts and he continued as head of the Research Department; the other part subsequently became the Picture Tube Division. In 1940, the Research Department undertook fundamental research in electronics and spectroscopy. This work was continued until 1941, when fundamental research was put aside in order that the activities of the staff might be devoted to war research. He was responsible for the establishment of the Physics Laboratory, Sylvania Electric Products Inc., Bayside, N. Y., and in 1944, became Manager of that laboratory. He has held several titles since that date, including that of Director of Engineering from 1951 to 1955, Director of Research from 1955–1958, and Vice-President of the Sylvania Research Laboratories from 1958 to 1959. In 1960, these laboratories became the General Telephone & Electronics Laboratories Incorporated, a subsidiary of General Telephone & Electronics Corporation. Dr. Bowie is Vice-President and General Manager of the Laboratories at Bayside.

He has made significant contributions to vacuum tube and television research, was chairman of Panel 19 of the National Television Systems Committee and is chairman of Panel 5 on Analysis and Theory of TASO. He has recently been appointed by the Governor of the State of New York to serve on the Advisory Council for the Advancement of Scientific Research and Development in New York State. He is also on the Advisory Committee of the Long Island Graduate Studies and Research Center of the Polytechnic Institute of Brooklyn, Brooklyn, N. Y.

Dr. Bowie is a Fellow of the American Physical Society and a member of Pi Mu Epsilon, Phi Lambda Upsilon, Phi Kappa Phi, Sigma Xi and Alpha Chi Sigma.

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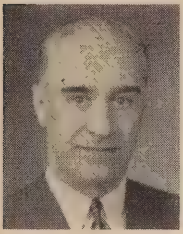
C. M. Braum

Cyril M. Braum (A'30–VA'39–SM'55) was born in Sacred Heart, Minn., on March 21, 1907. He received the B.E.E. degree from the University of Minnesota, Minneapolis, in 1929.

From 1929 to 1937, he worked in broadcast and police radio station engineering, and in theater and broadcast station sound equipment installation. He worked with the Federal Communications Commission from 1937 to 1953, in various capacities: as field engineer in Chicago, Ill.; as broadcast engineer in Washington, D. C.; as chief of the FM Broadcast Division in Washington; and as chief of the Television Broadcast Division in Washington. At present, he is engineering consultant for the Joint Council on Educational Television, Washington.

Mr. Braum is a member of the AIEE and the SMPTE.

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C. E. Dean

Charles E. Dean (A'29–M'36–SM'43–F'60) was born in Central, S. C., on May 23, 1898. He received the A.B. degree from Harvard University, Cambridge, Mass., in 1921, and the M.A. degree in physics in 1924 from Columbia University, New York, N. Y. During this period he also worked with the Engineering Department of the Western Electric Company, the predecessor of Bell Telephone Laboratories. He studied physics at The Johns Hopkins University, Baltimore, Md., from 1924 to 1927, and received the Ph.D. degree.

He then worked for two years at the headquarters of the American Telephone and Telegraph Company, New York, N. Y. From 1929 to the present, he has been working with the staff of the Hazeltine Research Corporation, Little Neck, N. Y. His work has included various patent studies and writing or editorial activity. During World War II he was responsible for the large volume of instruction books on equipment made by Hazeltine and numerous subcontractors. This work was recognized after the war by the award of a Certificate of Commendation from the U. S. Navy. From 1952 through 1956 he played a large part in the writing and editing of the comprehensive engineering text, "Principles of Color Television," John Wiley and Sons, Inc., New York, N. Y. In 1958 and 1959 he took an active part in the Television Allocations Study Organization, acting as chairman of Panel 6 on "Levels of Picture Quality."

Dr. Dean is a Fellow of the AIEE and the Radio Club of America and a member of SMPTE.

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G. L. Fredendall

G. L. Fredendall (A'41–SM'46–F'55) was born at Kettle Falls, Wash., on December 20, 1909. He received the Ph.D. degree from the University of Wisconsin, Madison, in 1936. From 1931 to 1936, he taught electrical engineering and mathematics, and engaged in research work in mercury-arc phenomena at the University of Wisconsin.

Since 1936, he has been with the Radio Corporation of America, working on systems research. At present he is located at the RCA Laboratories, Princeton, N. J.

Dr. Fredendall is a member of Eta Kappa Nu, Tau Beta Pi, and Sigma Xi.

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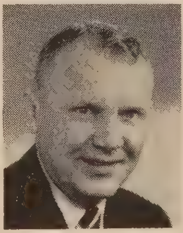
H. T. Head

Howard T. Head (A'52–SM'53) was born on December 15, 1919, in Oklahoma City, Okla. He received the B.S. degree from the University of Arkansas, Fayetteville, in 1941.

Prior to World War II, he was a junior engineer with RCA Laboratories, Camden, N. J. During the war, he held various assignments as a commissioned officer with the Signal Corps Engineering Laboratories. His last assignment was that of Chief of the Technical Staff of the Director of the Signal Corps Radar Laboratory, and he was retired from active service in 1945 with the rank of Major.

Since the war, he has been with the consulting engineering firm of A. D. Ring & Associates, Washington, D. C., in which he is now a partner. He was Chairman of TASO Committee 4.1 (Measurement of Television Service Fields) and Committee 5.4 (Theoretical Studies).

Mr. Head is President of the Association of Federal Communications Consulting Engineers and a member of the AIEE, the SMPTE, the AAAS, Sigma Pi Sigma, Pi Mu Epsilon, Phi Eta Sigma, Omicron Delta Kappa, and Phi Beta Kappa.

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W. L. Hughes

W. L. Hughes (S'48–A'50–M'55) was born in Rapid City, S. D., on December 2, 1926, He received the B.S.E.E. degree from South Dakota School of Mines and Technology, Rapid City, in 1949, and the M.S. and Ph.D. degrees in electrical engineering from Iowa State University, Ames, in 1950 and 1952, respectively.

He worked as a transmitter engineer for the Black Hills Broadcast Company of Rapid City, and was active in the engineering development of the Iowa State University television station WOI-TV. He was an Aviation Radio Technician in the Navy during World War II. From 1952 until 1960, he taught in the Iowa State University Electrical Engineering Department and directed research in color television systems and nonlinear circuits in Iowa State's Engineering Experiment Station. In April 1960, he became Professor and Head of the School of Electrical Engineering at Oklahoma State University, Stillwater.

He was active in TASO, being a member of Panels 3 and 6 and Chairman of Committee 3.3, which did most of the field work for Panel 3. He has been a member of the Administrative Committee of the Professional Group on Broadcasting of the IRE for five years and has been Editor of the Group's Transactions for two years. His consulting work has included the subjects of community television systems, subscription television systems, and aircraft collision problems.

Dr. Hughes is a member of the AIEE, SMPTE, and ASEE.

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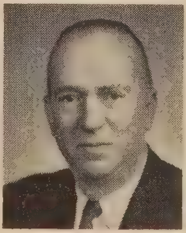
F. G. Kear

Frank G. Kear (A'24–M'31–SM'43–F'53) was born in Minersville, Pa., on October 18, 1903. He received the E.E. degree from Lehigh University, Bethlehem, Pa., in 1926, and the M.S. and D.Sc. degrees in electrical engineering in 1928 and 1933, respectively, both from the Massachusetts Institute of Technology, Cambridge.

He was associated with Dr. V. Bush in 1926–1928 in the development of the product integraph and the differential analyzer. From 1928 to 1933, he was engaged as a physicist in the Aeronautical Radio Group at the National Bureau of Standards. For the next eight years he was Chief Engineer of the Washington Institute of Technology, in charge of development of radio aids to air navigation. Since 1941, he has been a senior partner in the consulting engineering firm of Kear and Kennedy, Washington, D. C. During World War II, he was head of the Radio Section, Electronics Division, Bureau of Aeronautics, U. S. Navy.

Dr. Kear is a member of the SMPTE, the Association of Federal Communications Consulting Engineers, Eta Kappa Nu, Tau Beta Pi, Phi Beta Kappa, and Sigma Xi.

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S. W. Kershner

Stephen W. Kershner (A'43–M'55) was born in Texas on February 8, 1918. He received the B.S.E.E. degree from the University of Texas, Austin, in 1939.

He was employed for two years by the Texas Pipe Line Company at Houston, and was commissioned in the Signal Corps, U. S. Army, in 1941. During World War II, he was engaged in engineering work on radar equipment in England and later at the Signal Corps Engineering Laboratories, Fort Monmouth, N. J.

In 1945, he was released by the Army with the rank of Major, and since that time has been associated with the consulting firm of A. D. Ring & Associates, Washington, D. C. He has been a partner in the firm since January, 1953.

Mr. Kershner is a member of the American Geophysical Union, the AIEE, Eta Kappa Nu, and is a registered professional engineer of the District of Columbia.

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A. H. LaGrone

Alfred H. LaGrone (M'48–SM'51) was born in Panola County, Tex., on September 25, 1912. He received the B.S., M.S., and Ph.D. degrees, all from The University of Texas, Austin, and is a registered professional engineer.

From 1938 to 1942, he was a distribution engineer with the San Antonio Public Service Co., San Antonio, Tex. From 1942 to 1946, he was on active duty with the U. S. Navy. In 1946, he accepted the position of radio engineer with the Electrical Engineering Research Laboratory at The University of Texas. In 1954, Dr. LaGrone joined the faculty of The University of Texas and is now professor of electrical engineering.

Dr. LaGrone is a member of Sigma Xi, Tau Beta Pi, and Eta Kappa Nu.

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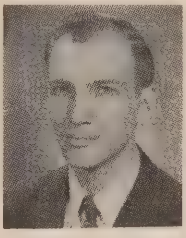
D. C. Livingston

Donald C. Livingston (S'51–A'52–M'52–SM'53) was born in Chicago, Ill., on August 13, 1921. He received the Ph.B. degree in physics at the University of Wisconsin, Madison, in 1943. From 1944 to 1946, he worked on the atomic bomb project at the Metallurgical Laboratory, Chicago, Ill., and at the Los Alamos Laboratory, New Mexico. He participated in the Bikini atomic bomb tests in 1946 as a member of the Los Alamos field group.

He pursued graduate studies in physics at the Ohio State University, Columbus, from 1946 to 1952. In January, 1952, he joined the staff of the Sylvania Research Laboratories at Bayside, N. Y. For the next two years, he worked on various problems relating to the analysis of color television systems and published several papers on that subject. In 1954, he initiated a project concerned with the development of electroluminescent information display devices. He is currently concerned with computer system research.

Mr. Livingston is a member of the American Physical Society and TASO.

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K. McIlwain

Knox McIlwain (A'31–M'40–SM'43–F'48) was born in Philadelphia, Pa., in 1897. He received the B.S. degree from Princeton University, Princeton, N. J. in 1918 and the B.S.E.E. and E.E. degrees from the University of Pennsylvania, Philadelphia, in 1921 and 1928, respectively.

From 1924 to 1941 he was a professor at the Moore School of Electrical Engineering, University of Pennsylvania. He was associated with the Hazeltine Electronic Corporation, from 1941 to 1957, as Chief Consulting Engineer. He was also previously associated with the Pennsylvania Bell Telephone Company.

Since early 1956, he has been with the Burroughs Corp., Paoli, Pa. As Manager of the Special Products Division, he was responsible for, organized, and directed all engineering development and design projects in the fields of digital communications, weapons systems, air defense instrumentation, airborne control systems, telemetering, and automation. He was formerly assistant to the Vice President of Research and Engineering, where he was responsible at the staff level for all facets of the Corporation's contribution to the Air Force Intercontinental Ballistic Missile Program. He is presently manager of the Great Valley Laboratory, a major division of Burroughs Research Center, conducting the great bulk of the Corporation's military development effort.

Mr. McIlwain is a member of Eta Kappa Nu, Phi Beta Kappa, Sigma Psi, and Tau Beta Pi.

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O. Prestholdt

Ogden Prestholdt (S'37–A'41–M'45) was born in Minneapolis, Minn., on April 5, 1917. He received the B.E.E. degree from the University of Minnesota, Minneapolis, in 1938.

For the next year and a half he taught mathematics at the University of Minnesota while continuing his studies in the fields of physics and engineering. From 1944 until the present, he has been employed in the Engineering Department of CBS, New York, N. Y. He is currently Manager, Radio-Frequency Measurements and Analyses, with responsibility for field strength surveys, radio wave propagation studies, and antenna design and performance. He has had more than twenty years of experience in the field strength survey field, including pioneer work on the UHF in 1946. He was an active member of TASO Panels 4 and 5, and made substantial contributions to TASO through work on Committees 3.3, 4.1, 5.1, 5.2, 5.3, and 5.4.

Mr. Prestholdt is a member of Eta Kappa Nu.

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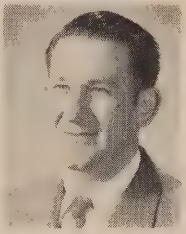

P. L. Rice

Philip L. Rice (M'52) was born in Washington, D. C. on December 25, 1922. He attended Lawrence College, Appleton, Wis., in 1941 and received the B.S. degree from the Principia College, Elsah, Ill., in 1948.

During World War II, he was commissioned at the Yale University Air Force Communications School, and spent 18 months in Brazil setting up and operating blind-landing systems for aircraft.

In 1948 and 1949, he was employed by the firm of Raymond M. Wilmotte, Inc., in Washington, D. C. Since that time, he has been a staff member of the Central Radio Propagation Laboratory of the National Bureau of Standards. He is Chief of the Tropospheric Analysis Section of the Radio Propagation Engineering Division at Boulder, Colo.

Mr. Rice is a member of the Institute of Mathematical Statistics and the Scientific Research Society of America.

William O. Swinyard (A'37–M'39–SM'43–F'45) was born in Logan, Utah, on July 17, 1904. He received the Bachelor's degree in mathematics and physics from Utah State University, Logan, in 1927, and has done graduate work at Columbia University, New York, N. Y., and Northwestern University, Evanston, Ill.

W. O. Swinyard

In 1930, he joined the Hazeltine Corporation in Bayside, N. Y.; in 1937 he was transferred to Chicago, where he has been chief engineer of Hazeltine Research, Inc., since 1942 and vice-president and director since 1958. He has published several articles in the field of electrical engineering.

Mr. Swinyard is one of the founders of the National Electronics Conference, and served the NEC as president and chairman of the board. He is a Fellow of the Radio Club of America and the AAAS; a Professional Member of Eta Kappa Nu; and past president of the Chicago Radio Engineers Club. He is a registered professional engineer, and a member of the National Society of Professional Engineers and of the Illinois Society of Professional Engineers. He is Chairman of Panel 2 (Receiving Equipment) of TASO.

❖

Holmes W. Taylor (M'52–SM'59) was born on October 25, 1925, in New York, N. Y. After serving in the U. S. Navy in World War II, he completed his courses at the Massachusetts Institute of Technology, Cambridge, receiving the B.S.E.E. degree in 1948.

H. W. Taylor

From 1948 to 1950, he was employed in the Electronics Division of Sylvania Electric Products, Inc. In 1950, he joined Burroughs Corporation, where he has been involved in the project management of data processing systems. He is currently on a staff assignment with the Great Valley Laboratory of the Burroughs Research Center, Paoli, Pa.

Mr. Taylor is a member of RESA and the Association for Computing Machinery.

❖

Harold G. Towlson (A'39–SM'47) was born in Gouverneur, N. Y. in 1908. He received the B.Sc. degree from Clarkson College of Technology, Potsdam, N. Y. in 1929 and the M.E.E. degree from Syracuse University, Syracuse, N. Y. in 1954.

H. G. Towlson

He joined the General Electric Company, Syracuse, N. Y. in 1929 in the Student Engineering Program, and has since worked for General Electric in various engineering and managerial capacities. These include assignments as Engineer in Charge of the South Schenectady Stations of General Electric, Project Engineer on High-Power AM Transmitters, and Manager of Engineering of the Broadcast Transmitter Section. Since 1957, he has been Manager-Engineering of the Technical Products Operation of Communications Products Department of the General Electric Company.

Mr. Towlson is a member of TASO and the EIA and is a Registered Professional Engineer in New York State.

❖

George R. Town (A'37–SM'44–F'50) was born in Poultney, Vt., on May 26, 1905. He attended Rensselaer Polytechnic Institute, Troy, N. Y. where he received the E.E. degree in 1926, and the D. Eng. degree in 1929.

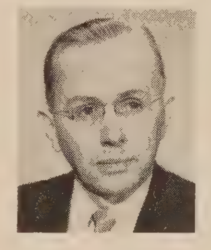
G. R. Town

He was an engineer in the research laboratory at Leeds and Northrup Company, Philadelphia, Pa., from 1929 until 1933. He then taught for three years at Rensselaer Polytechnic Institute. From 1936 until 1949, he was with the Stromberg-Carlson Company, Rochester, N. Y., where he was successively an engineer in the Research Laboratory, engineer in charge of the Television Laboratory, assistant director of Research, and manager of Engineering and Research. During this time he served actively on the first National Television System Committee and the Radio Technical Planning Board. In 1949, he joined the staff of Iowa State University, Ames, as associate director of the Engineering Experiment Station and professor of electrical engineering. For 20 months in 1956 and 1957, he was on leave of absence and served in Washington as executive director of the Television Allocations Study Organization. Since March 1, 1959, he has been dean of the College of Engineering at Iowa State University.

Dr. Town is a Fellow of the AIEE and a member of the National Society of Professional Engineers, the American Society for Engineering Education, Sigma Xi, Tau Beta Pi, Eta Kappa Nu, and Phi Kappa Phi.

❖

John E. Young (A'37–SM'48) was born in West Chester, Pa., in 1906. He received the B.S.E.E. degree from the Drexel Institute of Technology, Philadelphia, Pa., in 1928.


J. E. Young

On graduating, he joined the General Electric Company, Syracuse, N. Y., in their training course for radio engineers and contributed to the design of the first "Super-power Broadcast Transmitter," rated at 50 kw. He transferred to the Radio Corporation of America, Camden, N. J., in 1932 and participated in the design of the first transmitter job undertaken by the company. Since then, he has been concerned mainly with the design of broadcast transmitters and antennas, successively as a Design Engineer, Group Manager, and Section Manager.

Mr. Young is a member of TASO and the EIA.

Report of the Secretary—1959

To the Board of Directors
The Institute of Radio Engineers, Inc.

Gentlemen:

The Secretary's Report for the year 1959 is transmitted herewith and indicates, again, continued expansion of the IRE in all of its activities.

Net membership increased 11% to a total of 79,166. (See Fig. 1, and Tables I and II.) Professional Group membership increased 20% to a total of 87,027. Publications pages increased 18% and of these, Transactions pages went up 44%. Four special issues of the Proceedings appeared during the year, making possible the publication of additional valuable papers on timely subjects. Sight must not be lost of the important accomplishments of the twenty-five Technical Committees which, assisted by 119 subcommittees and task groups, held 233 meetings and issued four new Standards, in addition to which representation of IRE on 34 committees of the American Standards Association was provided for. IRE also sponsored three committees of this body.

It should be noted that your Headquarters' facilities have been foresightedly expanded suitably to care for this growth and additional steps have been taken for meeting the expected additional activities yet to come.

Respectfully submitted,

Haraden Pratt

Haraden Pratt
Secretary

January 31, 1960

Fiscal

A condensed summary of income and expenses for 1959 is shown in Table III, and a balance sheet in Table IV (opposite).

Editorial Department

The year 1959 saw the IRE publication program continue its rapid growth. During the year the IRE published 131 issues totaling 17,968 pages, an 18% increase over 1958. The increased publication output reflected the stepped-up program of Proceedings special issues and the fact that the Professional Group Transactions enjoyed the largest annual growth since their inception eight years ago.

Proceedings of the IRE

The year was highlighted by the appearance of four special issues: "The Nature of the Ionosphere—An IGY Objective" in February, "Government Research" in May, "Infrared Physics and Technology" in September, and "Bio-Medical Electronics" in

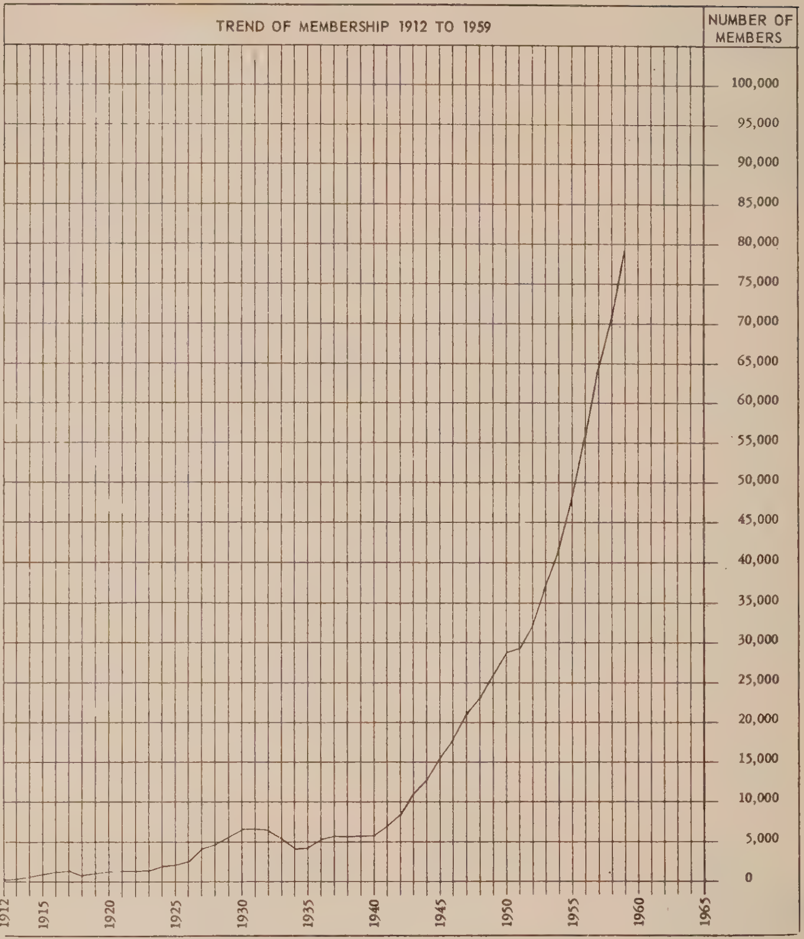


Fig. 1.

TABLE I

Comparison of Total Membership by Grades, 1957–1959

Grade	As of Dec. 31, 1959		As of Dec. 31, 1958		As of Dec. 31, 1957	
	Number	% of Total	Number	% of Total	Number	% of Total
Fellow	823	1	770	1.1	700	1.1
Senior Member	9,463	12	8,536	12.0	7,685	11.9
Member	38,977	49	32,373	45.4	26,115	40.3
Associate	13,165	17	14,721	20.6	16,827	25.9
Student	167,938	21	14,961	20.9	13,446	20.8
Totals	79,166		71,361		64,773	

TABLE II

Five-Year Analysis of Membership in U. S. and Other Countries

	1959	1958	1957	1956	1955
Total	79,166	71,361	64,773	55,494	47,388
U. S. and Possessions	73,044	65,786	59,961	51,551	43,977
Other Countries	6,122	5,575	4,812	3,943	3,411
Per Cent Other Countries	7.7	7.8	7.4	7.1	7.2

TABLE III

SUMMARY OF INCOME AND EXPENSE, 1959

Income		
Advertising	$1,597,469	
Member Dues and Convention	1,527,984	
Subscriptions	196,644	
Sales Items, Binders, Emblems, etc.	167,176	
Investment Income	40,676	
Miscellaneous Income	1,559	
TOTAL INCOME		$3,531,508
Expense		
PROCEEDINGS Editorial Pages	$ 540,922	
Advertising Pages	838,505	
Directory	277,172	
Section Rebates	80,147	
Student Program	137,658	
Professional Group Expense	225,737	
Sales Items	71,221	
General Operations	565,805	
Convention Cost	434,266	
TOTAL EXPENSE		$3,171,433
Reserve for Future Operations—Gross		$ 360,075
Depreciation		24,285
Reserve for Future Operations—Net		$ 335,790

TABLE IV

BALANCE SHEET—DECEMBER 31, 1959

Assets		
Cash and Accounts Receivable	$ 718,317	
Inventory	26,656	
TOTAL CURRENT ASSETS		$ 744,973
Investments at Cost	1,830,927	
Buildings and Land at Cost	974,140	
Furniture and Fixtures at Cost	251,519	
Other Assets	75,041	
TOTAL		3,131,627
TOTAL ASSETS		$3,876,600
Liabilities and Surplus		
Accounts Payable	$ 96,371	
TOTAL CURRENT LIABILITIES		$ 96,371
Deferred Income	1,022,280	
Professional Group Funds on Deposit	198,955	1,221,235
TOTAL LIABILITIES		$1,317,606
Reserve for Depreciation	100,939	
Reserve for Publications	30,000	
TOTAL RESERVES		130,939
Surplus Donated	595,287	
Surplus	1,832,768	
TOTAL SURPLUS		2,428,055
TOTAL LIABILITIES AND SURPLUS		$3,876,600

November. The resulting increase in the number of PROCEEDINGS papers from 183 in 1958 to 208 in 1959 was accompanied by an expansion of the Correspondence section from 180 letters to 209 letters. Consequently, the number of editorial pages reached an all-time high of 2370 pages, as shown in Table V and Fig. 2 (next page).

The increase in special issues was largely responsible for the 25% increase in the number of papers reviewed for the PROCEEDINGS, 363 papers totaling 2965 pages. Of these, 38% were accepted, 34% were referred to the TRANSACTIONS for publication consideration and 28% were rejected. Three IRE Standards and one Technical Committee Report also appeared during the year.

TRANSACTIONS

The health and vigor of the Professional Groups was unmistakably evidenced by a 44% increase in TRANSACTIONS output during 1959. As shown in Fig. 2 and Table VI, total pages increased from 5388 in 1958 to 7778. The total number of papers and letters published, 1068, for the first time accounted for more than half the total IRE output (1875).

IRE CONVENTION RECORDS

The 1959 IRE NATIONAL CONVENTION RECORD, published in 10 parts, contained 223 papers and 20 abstracts totaling 2116 pages, while the 8-part IRE WESCON CONVENTION RECORD contained 107 papers and 12 abstracts totaling 1008 pages. In an important innovation, the IRE WESCON CONVENTION RECORD was published in time for distribution at WESCON.

IRE STUDENT QUARTERLY

Four issues, totaling 224 pages, were sent free to IRE Student members during the year. In addition, approximately 24,000 free copies of the September issue were distributed to all non-IRE junior and senior electrical engineering students.

IRE DIRECTORY

A new photographic method for reproducing listings from typed cards was adopted for the membership listings in the 1960 IRE DIRECTORY, resulting in a substantial savings in cost. The DIRECTORY, which was published in November, contained 1312 pages including covers, of which 570 were membership listings and information and 742 were advertisements and listings of manufacturers and products.

CONFERENCE PUBLICATIONS

The *Proceedings of the 1959 Western Joint Computer Conference*, sponsored jointly by the IRE, AIEE and Association for Computing Machinery, was published by the IRE Editorial Department. The issue contained 364 pages including covers.

NEW PUBLICATIONS

Work on two new publications was gotten under way in 1959 for issuance during 1960. The first was a five-year cumulative index to all IRE publications which came out during 1954–1958. The second was an *IRE Dictionary of Electronic Terms*, containing all definitions of terms, graphical symbols and abbreviations which have appeared in IRE Standards over the past 15 years.

Technical Activities—1959

Technical Committees

During 1959, 25 Technical Committees and their 119 subcommittees held 233 meetings, of which 222 were held at IRE Headquarters and 11 throughout the nation.

Three IRE Standards and one Technical Committee Report, having been approved by the Standards Committee and the Executive Committee, were published in the PROCEEDINGS in 1959, and reprints are now available to the public.

IRE is directly represented on 34 Committees of the American Standards Association and sponsors three: The ASA Sectional Committee on Radio and Electronic Equipment, C16; the ASA Sectional Committee on Sound Recording, Z57; and the ASA Sectional Committee on Nuclear Instrumentation, N3. Two IRE Standards received approval of the American Standards Association as American Standards in 1959, and are now available overseas through the International Standards Organization.

IRE Technical Committees participated in international standardization in 1959 by reviewing and preparing comments on documents for the United States National Committee of the International Electrotechnical Commission.

Appointed IRE Delegates on Other Bodies

The IRE appointed delegates to a number of other bodies for the one-year period—May 1, 1959, to April 30, 1960 (as listed on page 44A of the October, 1959 PROCEEDINGS).

TABLE V

VOLUME OF PROCEEDINGS PAGES

	1959	1958	1957	1956
Editorial	2370	2199	1868	1996
Advertising	2760	2169	2700	2800
TOTAL	5130	4368	4568	4796

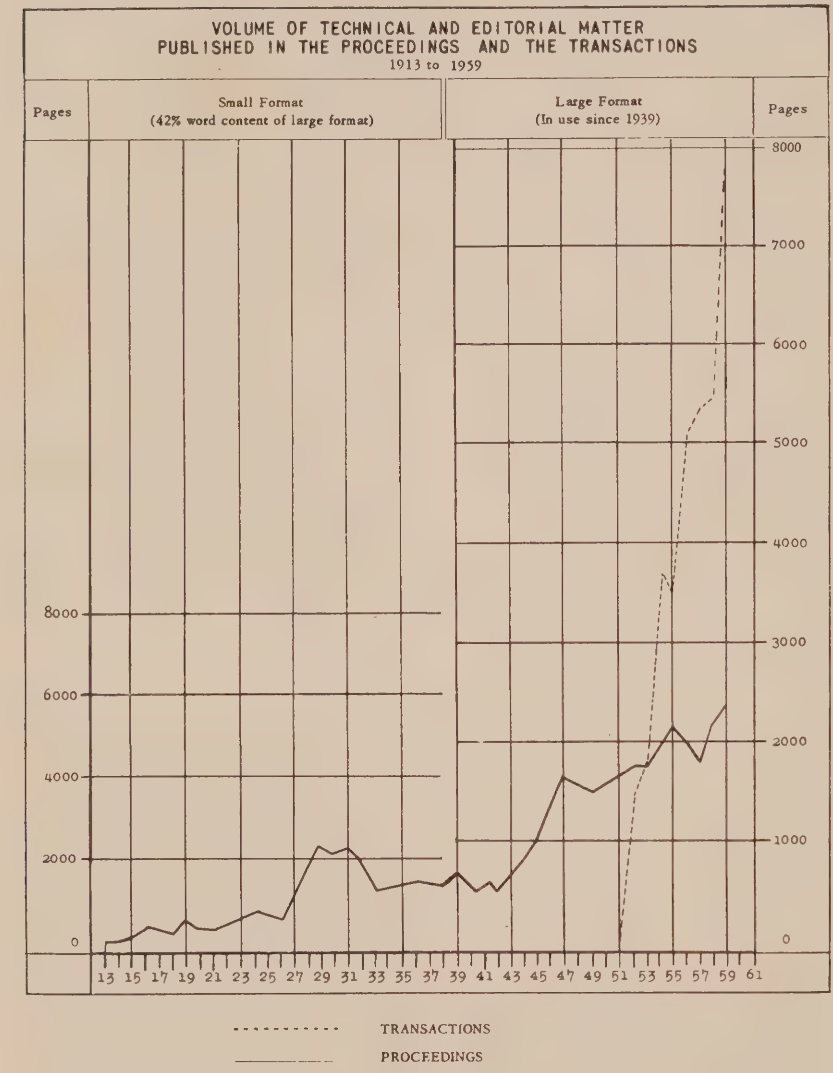


Fig. 2.

TABLE VI

VOLUME OF TRANSACTIONS PAGES

	1959	1958	1957	1956
Groups Publishing	27	26	24	23
No. of Issues	95	81	75	69
No. of Pages	7778	5388	5372	5044

The Annual Spring Meeting of the International Scientific Radio Union (URSI) was held May 5, 6, and 7, 1959, in Washington, D. C. The Fall meeting was held October 19, 20 and 21, 1959, in San Diego, Calif. The IRE Professional Groups on Antennas and Propagation, Circuit Theory, Information Theory, Instrumentation, and Microwave Theory and Techniques cosponsored these meetings. The XIIIth General Assembly of URSI will be held on September 5 through 15, 1960, at the University College of the University of London, London, England.

During 1959, the Executive Committee of the U. S. Preparatory Committee of the International Radio Consultative Committee (CCIR) held five meetings. At these meetings, the representatives of the fourteen Study Groups summarized and reported on their activities. Numerous responses to the questions under review by the Study Groups have been received in IRE during 1959. Lists of all material received from these organizations were distributed quarterly to the Chairmen of IRE Technical Committees and Professional Groups, as well as to The Joint Technical Advisory Committee.

The CCIR IXth Plenary Assembly was held at the Biltmore Hotel, Los Angeles, April 2 to 30, 1959. At this Assembly the United States' proposals were formulated for the International Telecommunication Union (ITU) conference which was held in Geneva beginning August 17, 1959, and ending December 18, 1959.

A report entitled "Radio Transmission by Ionospheric and Tropospheric Scatter," by the Joint Technical Advisory Committee, was circulated to all delegates at the Geneva conference in connection with the proposals being considered to amend the radio, telegraph and telephone regulations and to determine frequency allocations during the periods between international conferences.

The Joint Technical Advisory Committee (JTAC)

The Joint Technical Advisory Committee held a total of ten meetings for the period July 1, 1958, through June 30, 1959. The Eleventh Anniversary dinner was held in May, 1959.

Volume XVI, the cumulative Annual Report of the JTAC Proceedings was published in 1959. This included in Section I—Official Correspondence between the Federal Communications Commission and The Joint Technical Advisory Committee (IRE-EIA). Also included were items of correspondence pertinent to the activities of the JTAC. Section II of the Report contained the approved Minutes of Meetings of The Joint Technical Advisory Committee for the period July 1, 1958, through June 30, 1959.

The JTAC Subcommittee 55.1 on the Study of Forward Scatter Propagation, and its two working groups on Ionospheric Scatter Transmission, and Tropospheric Transmission rendered a report on "Radio Transmission by Ionospheric and Tropospheric Scatter." This was forwarded in preprint form to all delegates attending the CCIR Plenary conferences. This report will be published in the January, 1960, issue of the PROCEEDINGS OF THE IRE.

The International Electrotechnical Commission (IEC)

The International Electrotechnical Commission Subcommittee 12-1 on Measurements met in Ulm, Germany, from October 3 to 9, 1959. IRE secured the services of a delegate to represent the United States, and the IRE Technical Committees prepared this delegate on all items to be discussed at this meeting.

The annual meeting of the International Electrotechnical Commission was held in Madrid, Spain, June 30 to July 10, 1959. IRE did not actively participate in these meetings, since there were no meetings of IEC Technical Committee 12 on Radio Communication, or Technical Subcommittee 12-1 on Measurements scheduled at this time.

A list of all documents and material received in the Office of the IRE Technical Secretary from the IEC was distributed to the Chairmen of all Professional Groups, Technical Committees and Subcommittees.

Professional Group System

General: There are currently 28 Professional Groups operating actively within the IRE.

Approximately 65% of all IRE members have taken advantage of the Professional

Group System which now has a total membership of 87,027. Included are 5667 Student members of the IRE who have joined the Groups at the special Student member rate of $1.00 annually. Under the newly instituted Affiliate Plan, 421 scientists and medical doctors, whose major interests lie in fields other than electronics, have affiliated with a number of the Professional Groups.

All of the Groups have levied publications fees and their members are receiving the pertinent Group TRANSACTIONS regularly. In addition, a large number of company, university and public libraries have subscribed to the TRANSACTIONS of all the Groups. There is also a demand for individual Group subscriptions and individual copies of the TRANSACTIONS from outside sources.

Financial and editorial assistance were among the many services rendered by Headquarters to the Groups during 1959. The Office of the Technical Secretary provided administrative services for Group operations, the planning of meetings, advance publicity and the recording and mailing for all activities, including 838 mailings to Group members during the year.

Symposia: The procurement of papers and actual management of national symposia are entirely in the hands of the Professional Groups. Each of the Groups sponsored one or more technical meetings during this year, in addition to Technical Sessions at the IRE International Convention, the WESCON, The National Electronics Conference and other jointly sponsored meetings, for a total of 50 meetings of national import in 1959.

Publications: During the year, 27 Groups published 95 TRANSACTIONS containing 7778 pages. Since publication began in 1951, 487 issues (33,870 pages) have appeared. Full details on Group TRANSACTIONS are included in the Report of the Editorial Department.

Professional Group Chapters: 263 Professional Group Chapters have been organized by Group members in 58 IRE Sections. Chapter growth is continuing at a healthy rate. The Chapters are meeting regularly and sponsoring meetings in the fields of interest of their associated Groups in the various Sections.

Section Activities

We were glad to welcome five new Sections into the IRE during the past year. They are as follows: Benelux, Gainesville (formerly Subsection), India, Italy, and Orlando (formerly part of Central Florida Section).

The total number of Sections is now 105.

The Subsections of Sections now total 27, the following being formed in 1959: Reading (Philadelphia).

The following Subsections were dissolved in 1959: Palo Alto (San Francisco) and USAFIT (Dayton).

A growing major activity of many Sections and the larger Subsections in recent years is the publication of a local monthly Bulletin to fulfill the need for announcing to the Section members the increasing activities of the Section, including 1) Section meetings, 2) Professional Group Chapter meetings, and 3) Information on the local and national level of interest to the Section member.

Forty-eight of the Sections and Subsections are now issuing monthly publications.

Student Branches, 1959

The number of Student Branches formed during 1959 was 15. The total number of Student Branches is now 183, 118 of which operate as joint IRE-AIEE Branches and 15 as Student Associate Branches.

Following is a list of the Student Branches formed during the year: Air Force Institute of Technology, University of Alaska, University of Bridgeport, Devry Technical Institute, Duke University, University of Idaho, LaSalle College, University of Manitoba, Milwaukee School of Engineering, Mohawk Valley Technical Institute, New Bedford Institute of Technology, Northrop Institute of Technology, University of Puerto Rico, Royal Military College of Canada, San Jose State College (reestablished), University of Tennessee (reestablished), and West Virginia Institute of Technology.

IRE International Convention

The IRE Board of Directors, when discussing the IRE international activities in 1959, approved a change in name of the annual IRE Convention to "IRE International Convention and Radio Engineering Show." The 1959 Convention, held on March 23–26 at the Waldorf-Astoria Hotel and New York Coliseum, offered a program of 263 papers and 1200 exhibit units. A record total of 60,050 attended. This Convention continues to increase in importance each year and is internationally recognized as one of the largest conventions of its kind in the world.

It is with deep regret that this office records the death of the following members of the IRE during the year 1959.

Fellows

Goldup, Thomas E. (SM'52, F'52)
Morlock, William J. (A'43, SM'46, F'57)
Parker, Henry W. (SM'48, F'52)
Quarles, Donald A. (M'41, SM'43, F'54)
Ridenour, Louis N., Jr. (SM'52, F'55)
Van Der Pol, Balthasar (M'20, F'29, L'55)
Varian, Russell H. (A'40, SM'51, F'52)
Wheeler, Lynde P. (F'28)
Zenneck, Jonathan (F'48, L'56)

Senior Members

Allen, Donald H. (M'53, SM'54)
Beasley, William A. (A'44, SM'49)
Binns, John R. (A'26, SM'54)
Brady, John B. (A'20, M'29, SM'43)
Brown, James F. (SM'50)
Cater, John R. (S'41, A'44, M'52, SM'57)
Crossley, Alfred (A'19, M'26, SM'43, L'57)
Doane, John E. (A'41, M'44, SM'54)
Ebers, J. James (S'46, A'48, SM'53)
Friend, Halton H. (A'28, M'38, SM'43)
Given, Frederick J. (SM'49)
Guthrie, Frederick P. (A'16, M'28, SM'43, L'56)
Heiser, Edwin S. (A'28, SM'44)
Hoyler, C. N. (A'35, SM'45)
Jenssen, Matz (SM'55)
Kaulback, Harold D. (A'58, SM'59)
Kent, Roscoe (A'48, M'50, SM'50)
Kesgen, Edward W. (A'49, M'51, SM'58)
Lee, Emery H. I. (J'15, A'18, M'23, SM'43)
Lovejoy, Edwin W. (A'14, M'26, SM'43)
Maggio, John B. (M'42, SM'43)
Morse, Elwood K. (SM'58)
Nathan, Reuben (SM'54)
Peay, Lawrence W., Jr. (A'41, M'47, SM'55)
Ruth, Edward A., III (SM'52)
Sands, William F. (A'41, SM'46)
Stuckert, E. Morris (A'30, SM'47)
Tarboux, Joseph G. (SM'54)
Waldorf, S. K. (A'41, SM'45)
Waller, Bennie F. (SM'56)
Watson, Edward F. (M'45, SM'45)
Webb, James S. (A'17, SM'46, L'59)
Weedfall, W. W. (A'44, SM'58)
Wesser, C. H. (A'41, M'42, SM'43)

Members

Anders, Russell D. (A'43, M'55)
Atwood, William M. (S'58, M'59)
Barr, Ely E. (S'57, M'58)
Baruch, Sydney N. (A'44, M'55)
Baumbach, Earl J. (M'57)
Berman, Arnold D. (M'58)
Buck, Dudley A. (M'56)
Burns, John A. N. (M'58)
Canfield, Herbert H. (S'52, A'54, M'58)
Carlson, Harry A. (A'56, M'57)
Clanton, James D., Jr., (S'52, A'53, M'58)
Cox, Lemuel H. (M'47)
Croson, H. Lee (M'58)
Durham, Leland G. (S'45, A'50, M'55)
Ellsworth, John L. (S'52, M'56)
Frear, George C. (A'45, M'55)
Goldstein, William (A'52, M'58)
Gontermann, Adolf (M'56)
Green, Darrell B. (A'29, M'55)
Grimmett, Leonard J. (S'50, A'51, M'56)
Gyllstrom, Nylan D. (S'56, M'59)
Hamilton, Edwin E. (S'47, A'51, M'56)
Henderson, J. Alvin (A'50, M'58)
Hilson, Edward A. (M'57)
Hylkema, Chester G. (S'41, A'41, M'55)
Johnson, Marian S. (A'46, M'55)
Johnston, Edward L. (A'36, M'55)
Kleinberger, Robert (A'52, M'56)
Maring, Keith T. (M'54)
Marriner, Alfred W. (A'29, M'55)
Marsal, Paul A. (A'46, M'46)
Mathery, Lowell E. (S'49, A'51, M'58)
Meeker, Robert H. (M'57)
Morganstern, Richard I. (S'53, M'56)
Myers, Joseph R. (M'57)
Olson, Arthur J. (M'55)
Ossmann, Edward A. (A'45, M'55)
Poarch, M. F. (A'43, S'46, A'49, M'55)
Powers, Stephen J. (M'51)
Rappaport, Maurice B. (A'32, M'55)
Reber, John H. (S'47, A'49, M'55)
Robinson, Gordon D. (A'19, M'55, L'57)
Rothe, Mervyn E., Jr. (S'52, A'54, M'59)
Ruggi, Anthony G. (A'50, M'55)
Shortley, W. M. (A'42, M'55)
Sinclair, George W. (M'57)
Stein, Sidney (S'56, M'57)
Sutherlin, Robert F. (A'51, M'56)
Tweet, Ben O., Jr. (S'54, M'56)
Van Every, Bliss (A'46, M'58)
Walsh, Dorothy (S'51, A'52, M'57)
Welker, John J. (A'44, M'55)
Whiston, Raleigh W. (M'50)
Whittier, R. J. E. (M'54)
Wright, Robert A. (S'54, M'56)

Voting Associates

Coates, Archie L (A'35, VA'39)
Packman, M. E. (A'13, VA'39, L'51)
Ross, Kenneth B. (A'28, VA'39)

Associates

Allen, Harold A. (A'58)
Bolman, John G. (A'57)
Brown, Stanley F. (S'56, A'57)
Field, Charles (A'57)
Fitzgerald, Maurice W. (A'50)
Fogarty, Leonard L. (S'52, A'54)
Frankel, Samuel K. (A'56)
Hinrichs, Clair A. (A'54)
Kimes, Richard E. (S'49, A'51)
Nelson, Donald A. (A'44)
Phelps, Boyd (A'21)
Pierson, George E. (A'55)
Powers, Meredith L. (A'57)
Sheets, George (A'55)
Silvia, Everett R. (S'53, A'55)
Sonnenfield, Sigmund (A'57)
Spaeth, Charles A. (A'56)
Stewart, Edward A. (A'53)
Sussman, Albert B. (A'56)
Stinson, Lawrence W. (A'29)
Wetling, Thomas C., Jr., (A'58)

Students

Curti, Dino L. (S'56)
Frederickson, Albert L. (S'58)
Gardner, Jerry D. (S'58)
Morgan, Edgar W., Jr. (S'58)
Rosenbaum, Stanley H. (S'58)
Simmonds, Paul R. (S'57)
Tew, Loma O. (S'57)
Wakefield, Robert P. (S'58)

Books

Transistor Circuits, by K. W. Cattermole

Published (1959) by the Macmillan Co., 60 Fifth Ave., N. Y. 11, N. Y. 399 pages+8 index pages+9 bibliography pages+26 appendix pages+xi pages. Illus. $5\frac{3}{4} \times 8\frac{3}{4}$. $14.00.

The preface states that "this book gives an introductory account of the principal functions and circuit arrangements in which transistors can be used . . . its ideal reader is primarily interested in some field of usage; he is familiar with thermionic valves and electric circuits in general, but need have no more physics and mathematics than is normally consequent on that knowledge."

The first portion of the book (Chapters 1–4) discusses, in an elementary fashion, the properties of semiconductors, the manufacture of semiconductor devices, and their electric circuit properties. Chapters 5–7 treat low-frequency amplifiers, including multistage and power amplifiers, with considerable emphasis on feedback. Chapter 8 is devoted to high-frequency parameters and amplifiers with a comparatively detailed treatment of pertinent stability aspects. Tuned and wideband amplifiers are also discussed here, as well as feedback circuits at higher frequencies. Chapter 9 treats bias supplies and stabilization.

Chapters 10–14 deal with nonlinear circuits. Chapter 10 discusses the properties of negative resistances with emphasis on point-contact transistors. Chapters 11–13 cover large-signal transistor properties, bistable circuits, sinusoidal oscillators, pulse and other waveform generation, counting and timing circuits. Chapter 14 deals with transistor nonlinearities and their use in modulators, detectors, converters, automatic gain control circuits, and also discusses the accomplishment of some of these circuit functions by switching processes.

Chapter 15 discusses the measurement of transistor properties. Chapter 16 is entitled "Fields of Application" and surveys the use of transistors and their limitations in sound reproduction, television, radio receivers, telephone and telegraph systems, computers, power supplies and measuring instruments. The various appendixes provide the reader with background in specialized topics, such as linear network analysis, transient response of transistors, saturable magnetic materials, etc.

This British book has several interesting features and certainly adds a new flavor to existing treatments on transistor circuits. The qualitative discussions are often incisive and the circuit analyses generally thorough. Several topics, *e.g.*, feedback, are treated with more emphasis than has been done in other books.

In spite of its merits, this reviewer has reservations about the book. Its principal shortcoming is the lack of tie-in between physical properties on the one hand and circuit design on the other. For example, no attempt is made quantitatively to relate the frequency and bias dependence of transistor circuit properties to physical device parameters. It is therefore not surprising that the discussions on high-frequency equivalent circuits and power amplifier properties should appear at times disjoint. Further shortcomings are: excessive emphasis on point-contact transistors, somewhat ponderous mathematics which could be avoided by appropriate use of matrix algebra, inadequate number of tables which would enable the reader to use the book as a convenient reference, occasional misleading comments, some highly questionable conclusions based on the limitations of transistors available to the author at the time when the book was written, and absence of discussion on dc amplifiers.

In conclusion, this reviewer believes that this book could well be used by the practicing transistor circuit engineer as an *additional* reference volume. Its use as an introduction to transistor circuits, by the student or by the engineer unfamiliar with the subject, appears less attractive.

ARTHUR P. STERN
General Electric Co.
Syracuse, N. Y.

Ferrites, by J. Smit and H. P. J. Wijn

Published (1959) by John Wiley and Sons, Inc., 440 W. Fourth Ave., N. Y. 16, N. Y. 347 pages+5 index pages+17 bibliography pages+xiv pages. Illus. $6 \times 9\frac{1}{4}$. $10.00.

This is an excellent book dealing with the properties of magnetic oxides, such as ferrites and garnets. Those aspects of the theory of magnetism which are necessary for interpretation of the material properties are clearly described through the use of physical models and examples. Descriptions of numerous measurement techniques are interspersed throughout the text and tend to illustrate the significance of the properties being discussed. The organization and content of this book will make it very useful either as a text or a reference work.

JOHN H. ROWEN
Bell Telephone Labs.
Whippany, N. J.

The Birth of a New Physics, by I. Bernard Cohen

Published (1960) by Doubleday and Company, Inc., 575 Madison Ave., N. Y. 22, N. Y. 190 pages+5 index pages+5 pages guide to further reading. 34 figures. $4\frac{1}{8} \times 7\frac{1}{8}$. Paperback. $.95.

This book is one of the Science Study Series, a series of paperbacks the primary purpose of which is to provide a survey of physics within the grasp of the young student or the layman.

This particular volume, written by one of America's outstanding science historians, takes the reader through one of the most important chapters in the history of science, the development of Newton's law of universal gravitation and the laws of motion. Through the lives of Copernicus, Galileo, Kepler, and Newton, can be seen the dynamic advance of science, from speculative ideas through careful observations and empirical laws, to the crowning achievement of the synthesis by Newton.

The book is interestingly written, with emphasis on the progression of ideas. It cannot help but give a greater depth of understanding of science to those young students who may not go on in science. To those of us who have become scientists, it should help to fill in a gap which most of us have in our education, namely, a too frequent lack of knowledge of the basic history of science.

C. W. CARNAHAN
Varian Associates
Palo Alto, Calif.

Crystals and Crystal Growing, by Alan Holden and Phylis Singer

Published (1960) by Doubleday and Company, Inc., 575 Madison Ave., N. Y. 22, N. Y. 275 pages+14 index pages+31 appendix pages. 137 figures. 4⅛×7⅛. $1.45 (paperback).

This book in the Science Study Series—generally aimed at the high school level—has more than routine interest by the originality of its writing, the wealth of illustrations, and the person of its senior author, whose intuition has contributed several piezoelectric and ferroelectric crystals to the electronic art. The book starts out on an elementary level, but develops the important concepts of both classical and X-ray crystallography soundly, including a simple explanation of piezoelectricity. The book will be read with profit by the engineer who has never been exposed to crystallography but uses single crystal materials today. It is most welcome to those who are approached by young people for help in science projects.

Hans Jaffe
Clevite Corp.
Cleveland, Ohio

Linear Circuit Analysis, by B. J. Ley, S. G. Lutz and C. F. Rehberg

Published (1959) by McGraw-Hill Book Co., Inc.' 330 W. 42 St., N. Y. 36, N. Y. 560 pages+7 index pages+xvi pages. Illus. 6¼×9¼. $12.50.

This book is designed for "upper-class or first-year graduate students" as a text for "a course in linear, lumped-constant circuit theory." Most of the book is concerned with the solution of the integro-differential equations which arise in linear circuit analysis. Fourier series and integrals are introduced, and in addition some basic concepts in linear graph theory are used to establish the proof of the number of independent Kirchhoff's equations.

The book contains nine chapters, and opens with definitions of linear circuit elements, Kirchhoff's laws and network terminology. In Chapter 2, the topological proofs of a number of independent KCL and KVL equations and the matrix formulation of node and mesh equations are presented. Apparently the authors have made an effort to present linear graph theory in as easy a way as possible and the authors' aim seems to have been largely accomplished. However, it may be desirable to change some of the definitions. For instance, according to the definition of a node (page 10) a terminal which is common to two or more multiterminal elements, such as tubes and transistors, may not be a node without implying that their equivalent circuits consist only of two-terminal elements.

Chapters 3 and 4 discuss the solutions of linear integro-differential equations with constant coefficients for steady-state and transient analysis of circuits respectively. The chapters include the superposition theorem, phasor diagrams, driving-point admittance functions in terms of the node determinant and its cofactors, the concept of poles and zeros, various numerical methods of finding zeros of polynomials, etc. Chapter 5 contains the analogy between electrical and mechanical circuits. Chapters 6 and 7 present the theory of Fourier series and integrals and their application to circuit analysis. In Chapter 8, the theory and application of the Laplace transformation are discussed. Finally, in the last chapter, the concept of equivalent circuits and the use of Thevenin's and Norton's theorems and the reciprocity theorem are illustrated.

The reviewer feels that

1. Too many subsections with headings, and a number of "theorems" may not deserve the name;
2. The illustrations are wordy and tedious, particularly in the discussion of the number of independent Kirchhoff's equations.

The author's effort to "achieve logical completeness" in the contents of the book should be praised. However, some of the excess verbiage of the book may be eliminated if some more mathematical expressions are adopted. The book may prove useful to a student for the purpose of "first having an introductory treatment of the subject matter, to be followed later by a more advanced treatment which is not just a rehash of the earlier coverage but an extension of the subject matter that probes more deeply into it."

W. H. Kim
Columbia University
New York, N. Y.

Semiconductors, by R. A. Smith

Published (1959) by Cambridge University Press, 32 E. 57 St., N. Y. 22, N. Y. 481 pages+12 index pages+1 appendix page+xvii pages. Illus. 6¼×9¼. $12.50.

This book is one of a rather large number of semiconductor treatises which have appeared within the last few years, one of which, the reader should be aware, was written by the present reviewer. The book by Smith is one of the best of these, and one of the most advanced. It deals primarily with the basic theory of solids, the conduction and other theory of semiconductors, and gives a long and critical survey of the research done all over the world on the properties of the important semiconductors. Semiconductor devices are sketchily treated, entirely in one chapter.

The author, who is in charge of the solid state work at the Great Malvern laboratory of the Royal Radar Establishment in Great Britain, has covered very much the same ground as that covered by the reviewer's book, and by similar books by Spenke, Ehrenburg, and Hannay, with emphasis on the theoretical aspects. Of the 481 pages of text, 318 are taken up by the theoretical discussions before the entrance of 115 pages of discussions of the properties of semiconductors. Devices are covered in 48 pages at the conclusion of the book.

Considering first the coverage of the book in the field of basic semiconductor physics, this reviewer considers the work the best such survey that he has seen. This judgment is from the point of view of the advanced student of the field, and of the research worker. The book is very valuable in bringing up to date (1959) the latest work on band structure, transport theory, properties of silicon and germanium, and the properties of the compound semiconductors in which the author himself has made a first-class reputation. There is a short chapter on measurement techniques.

Considered as a text, this book will serve admirably for a graduate course in semiconductors, although the extent of the mathematical treatments and the extent of the explicit use of quantum mechanical equations and relations will make it appear somewhat too sophisticated for undergraduates. Its primary value, it must be supposed, however, will be as a reference and text for research workers already familiar with the field.

Insofar as this reviewer has had the opportunity to examine the quality of the work in detail, the book is very well done. The style is clear and the text quite understandable. The discussions are heavily documented with references to the original work. This practice, while it detracts somewhat from the clarity of the work as a text, greatly aids the researcher in keeping up with the literature.

Relatively few errors have been uncovered for a work of this size. Surprisingly enough a casual reading has, however, indicated the misspelling of fifteen or more authors' names both in the text and in the index.

In any work of this size covering a wide variety of topics exceptions can be taken to the emphasis given various topics, and to the evaluation of the work of others. On the whole, however, this book is an excellent one, which should take its place as one of the best of the advanced surveys of semiconductors.

W. C. Dunlap, Jr.
Raytheon Company
Waltham 54, Mass.

Recent Books

Gaynor, Frank, *Concise Dictionary of Science*. Philosophical Library, Inc., 15 E. 40 St., N. Y. 16, N. Y. $10.00

Harris, Lawson P., *Hydromatic Channel Flows*. John Wiley and Sons, Inc., 440 Fourth Ave., N. Y. 16, N. Y. $2.75. Presents analyses for 3 flows of viscous incompressible electrically conducting fluids in high-aspect-ratio rectangular channels subjected to transverse magnetic fields.

Helvey, T. C., *Moon Base—Technical and Psychological Aspects*. John F. Rider Publisher, Inc., 116 W. 14 St., N. Y., N. Y. $1.95. Story of the technical and psychological factors surrounding the first U. S. team of human beings—two men and a woman—to be sent to the moon.

Lurch, E. Norman, *Fundamentals of Electronics*. John Wiley and Sons, Inc., 440 Fourth Ave., N. Y. 16, N. Y. $8.25. An introduction to the field written for non-engineers and technicians.

Mandl, Matthew, *Fundamentals of Electronics*. Prentice-Hall, Inc., 70 Fifth Ave., N. Y. 11, N. Y. $10.60. A comprehensive detailed coverage of elementary principles. Provides a clear, understandable approach to modern developments.

Marton, L., *Advances in Electronics and Electron Physics*, Vol. IX. Academic Press, Inc., 111 Fifth Ave., N. Y. 3, N. Y. $9.00.

Neeteson, P. A., *Vacuum Valves in Pulse Techniques*, 2nd edition. The Macmillan Co., 60 Fifth Ave., N. Y. 11, N. Y. $5.50. Several methods are developed analyzing networks containing vacuum tubes subjected to large, suddenly applied signals, the tube being treated as a nonlinear network element.

The Radio Amateur's Handbook. The American Radio Relay League, Inc., West Hartford, Conn. $3.50. Written with the needs of the practical amateur in mind, the treatment of radio communication problems is in terms of how-to-do-it rather than abstract discussion.

Read, Oliver and Walter L. Welch, *From Tin Foil to Stereo.* Howard W. Sams and Co., Inc., the Bobbs-Merrill Co., Inc., Indianapolis 6, Inc. $9.95. An illustrated history of the phonograph.

Parker, William Vann and James Clifton Eaves, *Matrices.* The Ronald Press Co., 15 E. 26 St., N. Y. 10, N. Y. $7.50. Written for introductory college courses on the theory of matrices.

Williams, E. J., *Regression Analysis.* John Wiley and Sons, Inc., 440 Fourth Ave., N. Y. 16, N. Y. $7.50. Regression analysis is approached from both theoretical and applied viewpoints, emphasizing the practical problems of interpretation.

Wrigley, Walter and John Hovorka, *Fire Control Principles.* McGraw-Hill Book Co., Inc., 330 W. 42 St., N. Y., N. Y. $10.00. Attempts to resolve the existing multiplicity of viewpoints in the literature by separating the fire control problem from its solution, and the principles from the actual systems.

Scanning the Transactions

International. The importance of communication between engineers in different parts of the world is becoming increasingly evident. A growing number of international organizations are being formed in various technical fields to provide workers in different countries a greater opportunity for direct contact with one another. The IRE, with its recently renamed "International" Convention, its new constitutional provision for a Vice President residing elsewhere than in North America, and its Sections now operating on 5 continents, is itself an organization of rapidly growing international influence. In addition to society-type organizations like the IRE, however, there are a number of important federation-type organizations which have the very specific purpose of promoting scientific and technical progress on an international basis. One of the most recent of these is the International Federation of Automatic Control (IFAC). Founded in 1957, the IFAC is a federation of member organizations from 22 countries, each representing the technical societies interested in automatic control for the country it represents. The United States is represented in the IFAC by the American Automatic Control Council (AACC), and the IRE is represented in the AACC by the Professional Group on Automatic Control. The first major accomplishment of the IFAC is the holding of an international congress on automatic control in Moscow this year. IRE members are certain to hear more and more about the IFAC and the AACC and the important work they are doing during the coming years. (H. Chestnut, "The International Federation of Automatic Control," IRE TRANS. ON AUTOMATIC CONTROL, January, 1960.)

Parametric devices and masers have pretty much hogged the pages of technical journals and books during the past few years, resulting in a great many printed words on these two subjects. The volume of articles has reached a size where a bibliography would be a very useful, if not an indispensable, guide to the literature. One such bibliography has now been published which, because it is annotated, should be doubly valuable. Although restricted to books and periodical articles, it includes no less than 379 references. The bibliography reveals some interesting indications as to the role played by IRE publications in recording, and thus contributing to, the progress of these two important fields. Approximately one-fourth of the existing literature on parametric devices is contained in the pages of the PROCEEDINGS. When the TRANSACTIONS and CONVENTION RECORDS are taken into account, it turns out that the IRE has published 40 per cent of the articles on parametric devices and 20 per cent of the literature on masers. (E. Mount and B. Begg, "Parametric devices and masers: an annotated bibliography," IRE TRANS. ON MICROWAVE THEORY AND TECHNIQUES, March, 1960.)

Liquid helium is closely identified with the birth of the field of cryogenics. At normal atmospheric pressure, helium liquefies only when reduced to 4.2° K. The successful liquefication of helium has made it possible to cool other materials to temperatures within a few degrees of absolute zero, revealing new phenomena such as superconductivity and resulting in important device developments such as cryotrons and solid-state masers. Although liquid helium is thus best known as a cooling agent for studying the low-temperature properties of other materials, it has some rather startling properties of its own that are worth noting. For example, it is a superfluid. It can flow through narrow channels that are impervious to any other liquid and most gases. Its viscosity is an order of magnitude smaller than that of any gas, so small that it can't be accurately measured. Liquid helium has the remarkable property of being able to creep up the side of its container in apparent defiance of gravity. This can be demonstrated by lowering an empty beaker part way into a bath of liquid helium. A thin film of helium will force its way up the outside of the beaker, over the top and down, siphoning more helium from the bath into the beaker until the level in the beaker is the same as that of the bath. Liquid helium is also the best conductor of heat known to man, conducting a pulse of heat in much the same way that the atmosphere transmits sound. In fact, the transport of heat through liquid helium is often called "second sound." (A. Juster and P. K. Shizume, "Cryogenics—a survey," IRE TRANS. ON COMPONENT PARTS, March, 1960.)

More about polar blackouts. In recent years interest in the effects of auroral disturbances on communications has steadily increased until the Argus tests released a transient that is not likely to die out until a body of theoretical and experimental knowledge has accumulated to the point where the pertinent engineering questions have been answered. Adding to the existing data, trials of the Canadian Janet meteor-burst communication system were conducted in an auroral zone circuit during July, 1958 and from early December, 1958 until the middle of April, 1959. Tests performed in the vicinity of 40 megacycles indicated the vulnerability of the system to polar blackout and to excessive error rates with rapidly fluctuating auroral signals. Experimental data on the major blackout in July, 1959 are included. These data were obtained by the interesting technique of measuring the intensity of 30-megacycle cosmic noise emissions from the galaxy during a period when prominent solar flares were observed. The reduction in cosmic noise level which was measured after each solar flare provided data that are very useful in evaluating the increased absorption of VHF radio waves by the ionosphere during polar blackouts. (J. H. Crysdale, "Analysis of the Edmonton-Yellowknife Janet circuit," IRE Trans. on Communications Systems, March, 1960.)

Vector Algebra. Modern weapons and space control systems operate with inputs, outputs, and disturbances which may be characterized as vector quantities. These systems include devices such as coordinate converters, fire control, and guidance computers, gyroscopic instruments, and inertial navigation systems. One of the difficulties associated with three-dimensional problems is the physical visualization of the operation. This is especially true in dynamic problems where time as well as space is involved. Intuition and simple calculations often lead to the omission of important design factors related to inobvious dynamic coupling between system variables. To reduce these errors, a systematic vector notation may be used which breaks the continuum of motion into a series of static two-dimensional problems, in much the same way that the motion picture camera reduces continuum motion to a series of still pictures. This vector notation is developed and illustrated with several practical design problems in a three-part series of tutorial articles published by the Professional Group on Automatic Control. The first part of the article was published in May, 1959, and the second section discussing vector velocities has now appeared. (A. S. Lange, "Automatic control of three-dimensional vector quantities—Part 2," IRE Trans. on Automatic Control, January, 1960.)

Abstracts of IRE Transactions

The following issues of TRANSACTIONS have recently been published, and are now available from the Institute of Radio Engineers, Inc., 1 East 79th Street, New York 21, N. Y. at the following prices. The contents of each issue and, where available, abstracts of technical papers are given below.

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*** Libraries and colleges may purchase copies at IRE Member rates.**

Antennas and Propagation

Vol. AP-8, No. 1, January, 1960

Back Scattering Cross Sections of Cylindrical Wires on Finite Conductivity—E. S. Cassedy and J. Fainberg (p. 1)

The back scattering cross sections of fine wires, taking the effect of finite conductivity into account, have been found. The variational procedure is used to find theoretical expressions for the cross section and it is concluded that the zeroth and the first-order solutions of Tai converge to one another with the addition of loss, in the region of first resonance. For fine copper, platinum and bismuth wires, experimentally determined cross sections agree with the theoretical results calculated from the zero-order solution to within 4 per cent in peak resonant values and 1.5 per cent in bandwidth.

A Multipurpose Radar Target—J. W. Carr (p. 7)

Consideration of methods of simulating a moving target by making a mechanically stationary target appear [to an MTI (Moving Target Indicator)-equipped radar] to be moving resulted in the use of crystals as switching elements in a low-voltage low-energy battery-powered device. Extending the use of these switching elements results in a target that is visible to any polarization. By applying these concepts to composite waveguide structures, a dual-band simulated target head was developed and field tested.

On Uniform and Linearly Tapered Long Yagi Antennas—Dipak L. Sengupta (p. 11)

Traveling-wave analysis of long Yagi antennas is reviewed briefly. The method of designing a Yagi antenna from this viewpoint is discussed and some experimental results are given in order to verify the analysis. A long Yagi antenna, when designed according to the Hansen and Woodyard condition, has a sidelobe ratio of 9.32 db in its radiation pattern, irrespective of the length of the antenna. It is shown that by varying the propagation constant linearly along the length of the antenna, the sidelobe ratio can be improved considerably without sactificing much of the antenna gain. This linear variation of the propagation constant may be obtained by slowly tapering the element lengths and/or element spacings along the length of the antenna. An approximate theory is developed for the linearly tapered long Yagi antenna and it is verified by actual measurements. A comparison between the radiation patterns of the uniform and the tapered long Yagi antennas clearly shows the advantage of tapering.

Design of Circular Apertures for Narrow Bandwidth and Low Sidelobes—T. T. Taylor (p. 17)

This article extends a method of antenna design described in an earlier article by the same author. A family of continuous circular aperture distributions is developed in such a way as to involve only two independent parameters, A, a quantity uniquely related to the design sidelobe level, and $\bar{n}$, a number controlling the degree of uniformity of the sidelobes. An asymptotic approach to the condition of uniform sidelobes thus becomes possible. A companion article by Robert Hansen contains aperture distribution tables and examples.

Tables of Taylor Distributions for Circular Aperture Antennas—R. C. Hansen (p. 23)

Tables of the circular aperture distributions described in the preceding paper by Taylor are given. Steps in the design process are illustrated by examples.

High-Frequency Diffraction of Electromagnetic Waves by a Circular Aperture in an Infinite Plane Conducting Screen—S. R. Seshadri and T. T. Wu (p. 27)

The scattering of plane electromagnetic waves of wave number k by a circular aperture of radius a in an infinitely conducting plane screen of zero thickness and infinite extent is considered. In the limit of large ka and at normal incidence, the ratio of the transmission cross section to the geometrical optical value πa^2, is found up to the order $(ka)^{-5/2}$.

High-Frequency Diffraction of Plane Waves by an Infinite Slit for Grazing Incidence—S. R. Seshadri and T. T. Wu (p. 37)

The scattering of plane electromagnetic waves of wave number k by an infinite slit of width $2a$ formed by two perfectly conducting coplanar screens of zero thickness is considered. In the limit of large ka and at grazing incidence, the asymptotic series for the transmission cross section per unit length of the slit is evaluated up to the order $(ka)^{-11/2}$.

The Calculation of Reflector Antenna Polarized Radiation—Louis E. Raburn (p. 43)

A partly analytical process is described for calculating the far-zone patterns of reflector antennas which may have nonlinear polarization. Wave polarization equations are given for a focused but not necessarily symmetrical paraboloid. The process applies for any point-source feed whose radiation characteristics, including wave polarization, are known either by theory or measurements.

Calculated and measured patterns are given for a fan-beam antenna whose reflector is 120 λ high and 30 λ wide. They agree well near the axis and agree qualitatively for off-axis angles of several beamwidths. The sources of errors are discussed.

Maximum Angular Accuracy of Tracking a Radio Star by Lobe Comparison—Roger Manasse (p. 50)

A general expression is derived for the maximum angular accuracy of tracking a radio star by lobe comparison (or monopulse). This angular accuracy depends on the input signal-to-noise ratio, the wavelength, the time-bandwidth product of signal integration, and the effective length of the antenna aperture. The maximum angular accuracy can be obtained, approximately, by performing a simple correlation of odd and even components of the antenna output. Angular accuracy formulas for simple antenna dishes or for interferometers appear as special cases of the general result.

The Appendix discusses the interferometer technique in more detail, and the angular accuracy for the data processing technique used by M. Ryle is compared with that obtained from the optimum processing.

Experimental Studies of Meteor Echoes at 200 mc—J. L. Heritage, *et al.* (p. 57)

The paper describes experimental results of bistatic studies of meteor echoes at 200 mc using a high power source and highly directive antennas. The transmission paths studied ranged from 940 to 1800 km in length and included many off-great-circle paths. Diurnal burst rate curves are given for each path. Median duration of the VHF bursts is compared with theory. For certain paths, duty cycle and Doppler shift data are given. At some sites signals were received from ionization aligned with the Earth's magnetic field.

Scattering by an Infinite Array of Thin Dielectric Sheets—Robert E. Collin (p. 62)

By replacing each dielectric sheet in an infinite array of thin dielectric sheets by an infinitely thin polarization current sheet, a solution for the scattering of plane waves by such an array is obtained. The simplified periodic boundary value problem is rigorously solved by using bilateral Laplace transforms. Numerical results obtained compare favorably with those obtained by the Rayleigh-Ritz method.

Reciprocity Theorems for Electromagnetic Fields Whose Time Dependence is Arbitrary—W. J. Welch (p. 68)

Two reciprocity theorems are derived which are valid for fields whose sources may have arbitrary time dependence. The first theorem involves the electromagnetic potentials, and the second is in terms of the electric and magnetic fields directly. In both cases, it is necessary to make use of the advanced as well as the retarded solutions to Maxwell's equations. Some properties of the theorems are discussed, and, as an application, the second theorem is used to derive a variational expression for scattering of electromagnetic waves from a perfect conductor.

Frequency Scintillations of Satellite Signals Before and After the Argus Experiment—P. R. Arendt (p. 73)

Satellite signals are effected by frequency scintillations in the same manner as radio star emissions. Therefore, the Doppler shift of such signals suffers fluctuations. These alterations are a function of the variations of the electron density distribution along the radio-ray path under observation. The number and the magnitude of these scintillations are used to measure the roughness of the ionosphere (formation of a scintillation index). The paper deals with the alteration of the established scintillation index during a time interval in August and September, 1958, *i.e.*, before, during, and after the well-known Argus experiments. The observations indicate that no long-living ionospheric inhomogeneities were produced within the zones of the ionosphere which could be checked from our ground station.

Antenna Image Quality Evaluation—J. J. Myers **Part I—By an Optical Simulation Method** (p. 78)

An optical simulation method was used to study the effect of aperture illumination on image quality for a high resolution antenna. It was determined that an illumination close to uniform yields the best image, as measured by the similarity of the image to the object when similarity was judged by a group of human observers. The techniques used are described, and the results of the evaluation of a typical class of illuminations are given.

Part II—By a Medical Observer (p. 83)

A digital computer was used as a mechanical observer to evaluate antenna image quality as a function of the aperture illumination for a high resolution antenna. An illumination close to uniform was found to yield an image that was best as measured by the ease with which the mechanical observer was able to analyze the images. A description of the logical design of the observer and the results of applying it to the analysis of a typical class of illuminations are given.

Transmission-Line Missile Antennas—Ronald King, *et al.* (p. 88)

A class of protruding rocket antennas of low silhouette is analyzed in terms of an approximately equivalent circuit that consists of a shunt-driven transmission line terminated in a reactor at each end. Expressions for the currents in the several parts of the circuit are used to determine the Poynting vector and from this the radiation resistance referred to the current in the generator. The reactance is obtained from transmission-line formulas.

Radiation Pattern Synthesis with Sources Located on a Conical Surface—A. Ishimaru and G. Held (p. 91)

This paper presents various methods of synthesizing sources placed on a conical surface to produce a prescribed radiation pattern. The sources considered are a series of electric dipoles placed in free space on the surface of the cone around a set of circumferences. These circumferences are equidistant from each other, and the dipoles are oriented in the circumferential direction with no circumferential variation in intensity and phase.

A successive approximation method is employed to obtain the source function for those sources which are placed in a region where the circumferences measure approximately less than two wavelengths. For sources placed in the region where the circumference is less than approximately $(4/3)\pi$ wavelengths, an expansion formula of the product of the Bessel and exponential functions is employed. When the sources are located far from the cone tip, a method utilizing the maximum points of the Bessel function is used to compute the source function. In considering the beamwidth and the sidelobe level, the Tchebycheff pattern with the tapering effect is employed. Numerical examples are given to illustrate the effectiveness of the methods.

A Slot with Variable Coupling and Its Application to a Linear Array—Raymond Tang (p. 97)

The importance of a waveguide linear array capable of producing many different radiation patterns has led to the development of a slot radiator with variable coupling. An array of such radiators can be used as a laboratory apparatus for the evaluation of aperture distributions, or as a ground-pointing reconnaissance antenna operable at many different altitudes. The slot radiator consists of a longitudinal slot centered in the broad face of a rectangular waveguide. An adjustable iris excites the slot by introducing controlled asymmetry in the waveguide fields. The theory of operation and the characteristics of this variable coupling slot are presented. These characteristics are shown in curves usable for design purposes. A detailed discussion is given of the technique used in determining the range of conductances of this slot. The control of coupling available is demonstrated by measured radiation patterns on a 12-element array in which the conductance values are varied to obtain sidelobe ratios from 10 to 34 db. The method used in obtaining the aperture distributions for these radiation patterns is also presented.

Communication (p. 102)

Contributors (p. 123)

Announcement of IRE-URSI Joint Spring Meeting (p. 126)

Annual Index, 1959 (follows p. 126)

Audio

Vol. AU-8, No. 1,

January/February, 1960

The Editor's Corner—Marvin Camrax (p. 1)

PGA News—J. R. Macdonald (p. 2)

Calibration and Rating of Microphones—William B. Snow (p. 5)

Calibration of a microphone consists of measuring its response to some known characteristic of a sound field under specified conditions. Usually the open circuit voltage for a one-microbar sound pressure is determined. Calibrations in an anechoic chamber give plane wave response, while those in a reverberant room give the response to sound arriving from all directions—at random incidence. Techniques have been developed for measuring response with considerable efficiency. Calibrations can be made with pure tones or with wideband signals such as noise or warbled tones. Complete calibration includes measurements of directivity and impedance as well as linearity of response. From the calibrations it is possible to calculate ratings which give quick and relatively fair comparisons between microphones. The RETMA Rating is particularly effective for the commercial types with impedance below 200,000 ohms. For small crystal and condenser microphones a statement of the noise threshold is more indicative of true performance capability. Although complete specification of microphone performance requires considerable information, the ratings dispel the main ambiguities in response figures arising from differences in impedance, circuits and test sound pressures.

Stereophonic Projection Console—B. B. Bauer and G. W. Sioles (p. 13)

A system is described for home stereophonic reproduction from a single cabinet by reflection of sound from the room boundaries. The effect is emphasized by using loudspeakers which maintain a uniform cardioid directional pattern over the useful frequency range. The directional properties are obtained with acoustic phase-shift networks.

A Transistorized Stereo Preamplifier and Tone Control Magnetic Cartridges—Alexander B. Bereskin (p. 17)

RIAA equalization with ±4 db bass control and ±8 db treble control have been achieved, along with negligible hum, noise and distortion, in a transistorized stereo preamplifier developed for use with magnetic cartridges. Simple circuit modifications adapt this preamplifier for use with most magnetic cartridges.

Bandwidth Compression by Means of Vocoders—Frank H. Slaymaker (p. 20)

Speech information may be transmitted over a bandwidth one tenth of that required for the original speech if attention is directed toward reproducing the envelope of the power density spectrum rather than the waveform itself. Pitch information can be transmitted independently of the spectrum information and the two sets of signals combined at the receiving end to resynthesize the original speech sounds. In the vocoder the power spectrum is analyzed and synthesized by means of band-pass filters. The energy for the voiced sounds is obtained from an oscillator called a buzz source, and for the fricative consonants the energy is obtained from a white noise source.

Design and Use of *RC* Parallel-*T* Networks—Gifford White (p. 26)

The *RC* parallel-*T* network with a transmission null at f_0 is described and the symmetrical lattice approach to its analysis is outlined, following a notation of Guillemin. The selection of design parameters for various principal applications, with relevant references to published work, is given.

The common applications requiring a response curve symmetrical about f_0, such as the single-frequency notch filter, the ac derivative network and the frequency discriminator are treated. In this class falls the feedback amplifier with a very narrow notch.

The use of the parallel-*T* as a low pass or a high pass is covered briefly, and it is shown how a net of more complexity can be derived to give an improvement in response. Using the symmetrical lattice equations, typical examples are worked out. The resulting networks are usually three *T* nets in parallel, or a triple-*T*. A simple feedback amplifier for obtaining a response equal to an m-derived *LC* filter is described as a further solution to the problem.

Typical feedback amplifier circuits giving either one-pole or two-pole response are presented. The detailed analysis of a two-pole *RC* feedback net is given, followed by practical design equations and experimental response data.

The engineering problem of component selection for network stability is discussed, since this is a major consideration in designing satisfactory circuits. Frequently, stability is the only problem not readily solved by the potential user. Temperature compensation techniques are given, together with typical experimental data on temperature errors.

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Automatic Control

Vol. AC-5, No. 1, January, 1960

Foundations of Control—the Editor (p. 1)

The Issue in Brief (p. 2)

The International Federation of Automatic Control—Harold Chestnut (p. 3)

The initials IFAC, standing for the International Federation of Automatic Control, are appearing more and more in the control systems literature these days. It is appropriate that readers of these Transactions be more fully aware of this organization in which they participate through the IRE's membership in the American Automatic Control Council. What are IFAC's purposes, who are its members, how does it operate, what has it accomplished? Now, after two years of existence for IFAC, these data are better known and have more significance.

Dynamic Programming and Adaptive Processes: Mathematical Foundation—R. Bellman and R. Kalaba (p. 5)

In many engineering, economic, biological and statistical control processes, a decision-making device is called upon to perform under various conditions of uncertainty regarding underlying physical processes. These conditions range from complete knowledge to total ignorance. As the process unfolds, additional information may become available to the controlling element, which then has the possibility of "learning" to improve its performance based upon experience; *i.e.*, the controlling element may *adapt* itself to its environment.

On a grand scale, situations of this type occur in the development of physical theories through the mutual interplay of experimentation and theory; on a smaller scale they occur in connection with the design of learning servomechanisms and adaptive filters.

The central purpose of this paper is to lay a foundation for the mathematical treatment of broad classes of such *adaptive processes*. This is accomplished through use of the concepts of dynamic programming.

Subsequent papers will be devoted to specific applications in different fields and various theoretical extensions.

The Properties and Methods for Computation of Exponentially-Mapped-Past Statistical Variables—Joseph Otterman (p. 11)

The exponentially-mapped-past (emp) statistical variables represent an approach to the statistical analysis of a process when the interest is focused on the recent behavior of the process. An exponential weighting function decreasing into the past, in the case of continuously observed processes, and a geometric ratio, in the case of discrete data, are utilized. This approach is the simplest from the point of view of ease of computation, and at the same time it possesses the advantage of some simple theoretical relationships, which are discussed. Analog computer circuits and digital computer flow diagrams which serve to compute the exponentially-mapped-past statistical variables are presented.

Generalized Weighting Function and Restricted Stability of a Linear Pulse-Modulated Error Feedback System—William A. Janos (p. 18)

A generalized weighting function is obtained for a linear feedback system with a pulse-modulated error signal. This is expressed in the form of a matrix operator acting on an input vector, the components of which are the first $R-1$ derivatives of the input, where R is the order of the unmodulated closed-loop system. In addition, since the system operator takes the form of a finite dimensional matrix, it has been possible to make and realize more stringent conditions on the transient stability; namely, a preassigned bounded output after a preassigned time.

Although the solution has been obtained generally for nonuniform pulsing, the latter stability investigation has been made only for the uniform case.

Optimization Based on a Square-Error Criterion with an Arbitrary Weighting Function—G. J. Murphy and N. T. Bold (p. 24)

Several important criteria for the performance of communication systems and control systems are reviewed, and a new criterion (the mean-weighted-square-error criterion) is then introduced. This is shown to be a special form of a very general criterion proposed earlier, but to have special significance in that it is a generalization of the familiar mean-square-error criterion.

The minimization of the mean-weighted-square error is treated in detail, and a solution for the optimum physically realizable frequency function of the system is given.

Multiple-Rate Sampled-Data Systems—Lester A. Gimpelson (p. 30)

The characterization of multiple-rate sampled-data systems by the ordinary z-transform of single-rate systems is shown. Single-rate sampling, or impulse modulation, of continuous signals is performed by an impulse modulator, M; the sampled, or "starred," function is described by the z-transform. In an analogous manner, a submultiple-rate modulator is introduced; its presence in a branch allows the passage of every nth pulse, or a train of pulses at a submultiple rate; the nomenclature of single-rate systems is continued through the performance of submultiple-rate "starring" of discrete signals and discrete filters. Table I permits starred expressions to be rewritten as functions of the z-transform in closed form. Techniques are shown for the reduction of discrete, and mixed continuous and discrete systems via flow graphs, so that, after the modulators are removed from the feedback loops, the analysis may proceed by standard methods. Representation of single- and submultiple-rate modulation in the s- and z-planes is used to demonstrate that submultiple-rate modulation of discrete signals is analogous to the impulse modulation of continuous signals.

Automatic Control of Three-Dimensional Vector Quantities—Part 2—A. S. Lange (p. 38)

In Part 1 of this paper a vector algebra was developed using a three-element column matrix to represent the vector, and a three-by-three matrix to represent a vector transformation operator. Problems in spherical trigonometry were analyzed with the use of a position vector, and the design of automatic computers to solve such problems was considered. In Part 2, the angular velocity vector is introduced for the purpose of analyzing and designing geometric stabilization systems.

Root Locus Properties and Sensitivity Relation in Control Systems—Hanoch Ur (p. 57)

The differential properties of root loci including pole sensitivity, angle of slope, and curvatuve at ordinary and irregular points are investigated in a unified manner. A relation between the sensitivity function and pole sensitivity is established. The sensitivity is shown to determine variations in the transfer function due to large (not only infinitesimal) variations in K. Additional properties of loci which are developed include loci of a variable pole position and the existence of asymptotes for open-loop transfer functions with no poles or zeros at infinity.

The locus is treated as a transformation of a line (the real axis) in the K plane to the s plane, and properties of analytic functions are used to simplify calculations and results. It is shown that the properties obtained can be extended to the general root locus of a nonreal K.

Time Lag Systems—A Bibliography—N. H. Choksy (p. 66)

In a recent tissue of IRE Transactions on Automatic Control, Weiss has given an excellent annotated bibliography on the subject ot transporation lag. He was kind enough to refer to a previous bibliography which appeared in this author's thesis (his reference number [Ch 5]). Since the latter is not generally available, the bibliography therein is given here. The items which have already appeared in Weiss' listing have been omitted; items which have appeared since the thesis was written have been included.

While most of the items here were found by library searches, acknowledgment must be made to Bellman's bibliographies as a source.

If there are items which have not been mentioned either here or in Weiss' paper, the author of the present paper would appreciate being informed about it by either a complete reference or a copy of the paper (or paper) in question.

A short introduction on the mathematical characterization of time lag systems is given before the bibliography.

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PGAC News (p. 75)

Communications Systems

Vol. CS-8, No. 1, March, 1960

Frontispiece and Guest Editorial—J. E. Schlaiker (p. 1)

Inverse Ionosphere—George D. Hulst (p. 3)

The distortion introduced into a long-range communication system by unpredictable multipath conditions of the ionosphere is described in this paper. A device to eliminate this particular form of distortion is then described, using a sensing technique, a logical matrix, and a signal restoration network. Since both the multipath model of the ionosphere and the restoration network are linear, the principles of suserposition apply to the cascaded combination so that the described technique is generally applicable to all waveforms. Specific restoration networks are described for several typical ionosphere multipath conditions. The effects of white noise upon the correction network and the signal are noted. The inverse instrumentation can be placed in the system either as a restoration network at the receiver or as a pre-distorting network at the transmitter.

Pain-Loss Measuring Techniques and Equipment—J. Polyzou and M. Sassler (p. 9)

The planning of tropospheric scatter communication systems requires precise and reliable knowledge of the path loss. This paper describes the techniques and equipment used to evaluate proposed installations. The equipment operates in the frequency range of 875 to 940 or 1650 to 1950 mc with output powers of 10 or 100 watts. A logarithmic recording system is used which makes possible a dynamic signal recording range of 50 to 100 db. Automatic frequency control is employed to achieve a 300-cps 3-db bandwidth with moderate oscillator stabilities.

Optimum Antenna Height for Ionospheric Scatter Communication—R. G. Merrill (p. 14)

Radiation patterns of elevated antennas over spherical earth for scatter propagation in the lower ionosphere incorporating refraction, parallax, spherical divergence, tropospheric defocusing, and near-horizon diffraction have been used to compute the height gain function resulting from raising and lowering symmetric transmitting and receiving antennas for a fixed path length. This height gain function shows that a broad range of *lower* antenna heights has a gain over that antenna height computed with the same model which places the maximum of the first lobe at the path midpoint. The maximum of this function is defined as the optimum antenna height.

Results from a Three-Hop Tropsopheric Scatter Link in Norway with Parallel Operations on 900 mc and 2200 mc—H. N. Knudtzon and P. E. Gundmanson (p. 20)

A three-hop troposcatter system in Norway with simultaneous operation at 900 mc and 2200 mc is described briefly. From measurements on a 360-km hop in the period October 1957 to June 1958, it is concluded that 1) the monthly amplitude distributions are approximately Gaussian, and the 1-minute amplitude distributions are approximately of the Rayleigh type, 2) the signals are generally considerably stronger (differences up to the order of 10 db) in summer than in winter, 3) the monthly median strength of the 900-mc signals is generally 0–2 db stronger than that of the 2200-mc signals, 4) the foreground conditions may be critical, 5) the 1-minute fade duration distributions are approximately log-normal, 6) there are indications that the normalized 1-minute fade duration distributions are about equal for 900 mc and 2200 mc, 7) considerable reductions in telegraph error rate are effected by increasing orders of diversity reception, 8) the telegraph error rates are equal for 900-mc and 2200-mc signals of equal median strengths, 9) frequency-modulated telegraph multiplex equipment is slightly superior to two-tone telegraph multiplex equipment, when adjusted to equal loadings, 10) antenna radiation diagrams depend critially on local surroundings, such as woods.

Performance of a 640-Mile, 24-Channel UHF-SSB Experimental Communication System—Burt E. Nichols (p. 26)

A mock-up Communication system has been installed between Westford, Massachusetts, and Winston-Salem, North Carolina, providing a 640-mile path as a test circuit to measure performance of a 24-channel UHF-SSB system. The equipment is described, the theoretical performance of the system is given, and the performance of the system as to voice quality and signal-to-noise ratio in a telephone channel and simulated teletype error count is shown.

Analysis of the Performance of the Edmonton-Yellowknife Janet Circuit—J. H. Crysdale (p. 33)

Trials of the Canadian Janet B system were carried out on an auroral zone circuit during July, 1958, and from early in December, 1958, until the middle of April, 1959. The July, 1958 trials, which were performed at frequencies in the vicinity of 40 mc, revealed the vulnerability of the system to polar blackout at these frequencies and to excessive error rates with rapidly fluctuating auroral signals. The objective of the trials carried out between December, 1958, and April, 1959, was the accumulation of long-term statistical data. The test message and operational procedures were designed to permit detailed analysis with an IBM 650 computer. Some preliminary results are included in this paper. Because of the basic importance of the polar blackout problem, pertinent experimental data concerning the major blackout of July, 1959, are presented and discussed.

Data Transmission Tests on Tropospheric Beyond-the-Horizon Radio System—F. E. Willson and W. A. Runge (p. 40)

This paper presents the results of data transmission tests made on both single-link and multi-link tropospheric beyond-the-horizon radio systems. Tests were made at 750 or 1300 bits per second employing both double sideband AM and FM methods of data modulation. In the single-link tests the data performance was determined for various transmission parameters such as median channel noise, peak channel noise, radio received carrier level, and order of diversity.

Data were satisfactorily transmitted on a 2400-mile circuit consisting of nine different beyond-the-horizon paths and six line-of-sight paths. The FM-type data modulation was notably superior to the AM type.

A Frequency Stepping Scheme for Overcoming the Disastrous Effects of Multipath Distortion on High Frequency FSK Communication Circuits—Arthur R. Schmidt (p. 44)

By changing frequency a small amount after transmission of each signaling element in FSK transmission, it is possible to avoid the mutual interference of the main and multipath propagated signal in a high-frequency communications system. Thus, it is practical to employ four-channel time division multiplex systems under multipath conditions that would otherwise render them useless.

This paper describes an experimental system that was produced by modifying conventional FS keyers and employing standard communications receivers in conjunction with appropriate frequency stepping means and selective filters. Operational performance data on experimental circuits will be discussed.

Transmitter Power Control in Two-Way Communications System—G. S. Axelby and E. F. Osborne (p. 48)

A typical scatter communications loop consists of two sites, each having transmitters and receivers operating simultaneously over a two-way microwave loop. In tropospheric scatter systems, disturbances in the microwave paths produce dynamic fading of RF signal levels at the receivers. To achieve high system reliability the current practice is to continuously transmit high power, adequate to maintain RF reception during the presence of severe fading. This wastes power and creates serious radio interference during favorable propagation periods.

Feedback control is applied to high reliability systems to vary the transmitted power as a function of the fading and consequently 1) to reduce operating cost by conserving transmitted power, and 2) to reduce interference to other radio networks in the area.

Other secondary advantages, including reduction of the dynamic range of received signal strength (which will ease receiver AGC and RF amplifier design), will be apparent to the reader. In order to maintain high system reliability, the automatic control at each site is simultaneous, continuous, and effective for nonreciprocal as well as for reciprocal fading. The system has been referred to as Controlled Carrier Communications.

The Sum of Log-Normal Probability Distributions in Scatter Transmission Systems—Lawrence F. Fenton (p. 57)

The long-term fluctuation of transmission loss in scatter propagation systems has been found to have a logarithmic-normal distribution. In other words, the scatter loss in decibels has Gaussian statistical distribution. Therefore, in many important communication systems (*e.g.*, FM), the noise power of a radio jump, or hop, has log-normal statistical distribution. In a multihop system, the noise power of each hop contributes to the total noise. The resulting noise of the system is therefore the statistical sum of the individual noise distributions.

In multihop scatter systems and others, such as multichannel speech-transmission systems, the sum of several log-normal distributions is needed. No exact solution to this problem is known. The discussion presents an approximate solution which is satisfactory in most practical cases. For tactical multihop scatter systems, a further approximation is proposed, which reduces significantly the necessary computation. An example of the computation is given.

Intermodulation Distortion and Efficiency Analysis of Multicarrier Repeaters—F. Assadourian (p. 68)

Under suitable conditions a common RF repeater may be used to amplify a number of modulated carriers. The basic limitations are efficiency and intermodulation distortion introduced within the frequency band of any modulated carrier wave by the other modulated carrier waves. Any repeater contains a high-power tube for which the output-input characteristic has nonlinearities that introduce a certain amount of intermodulation distortion. Over the useful range of input levels one usually finds that high efficiency and large distortion occur at high levels and low efficiency and low distortion at low levels. The range of acceptable distortion is determined by the intended application and in turn determines an efficiency range. This paper will obtain relationships between distortion or efficiency and input power for a third-degree nonlinearity. Although similar problems have frequently been treated previously in the literature, it is felt that the present approach offers a fresh point of view.

The following assumptions will be made in the present analysis. It is assumed that the repeater has a bandwidth which accommodates the combined bandwidths of the modulated carriers but is small compared to any frequency within it. For this case the only intermodulation components in the output are of odd order. It is also assumed that the unmodulated carriers are equally spaced within the repeater pass band and have equal levels. Such a spacing should yield pessimistic distortion predictions since it is well known that they can be improved by resorting to suitable unequal spacing. For equal carrier spacing and a large number of channels it turns out that intermodulation distortion is essentially independent of carrier spacing and the exact size of the narrow repeater bandwidth. Another assumption is that the frequency transfer characteristic of the repeater is flat in amplitude and linear in phase over its pass band.

The following basic procedure in the distortion and efficiency analysis of a repeater is set up for any kind of power tube in the repeater. The repeater output-input characteristic is assumed to be known in terms of power levels at any frequency within the repeater pass band. This power characteristic is then converted into an equivalent voltage characteristic in terms of output and input peak voltages and finally into an equivalent "instantaneous" voltage characteristic which is used for multicarrier inputs. The input modulated carriers, which may be PCM-FM, for example, are replaced by two extreme cases. In one case they are replaced by unmodulated single-sideband tones of the same total power as the modulated carriers. In the second case they are replaced by flat Gaussian noise of the same total power. Distortion results for the actual case of modulated carriers should be between the corresponding results for the two extreme cases. It is apparent that the present approach does not depend on a particular type of carrier modulation.

The above type of analysis is made with either "envelope" or "instantaneous" voltage characteristics which can be approximated by odd-order cubic expressions and can be extended to cover higher odd-order approximations. Intermodulation distortion and efficiency predictions are then made in terms of the coefficients of the approximating cubic. The analysis is later applied to a klystron power amplifier. The results are plotted in the form of signal to intermodulation power and efficiency curves vs a "bunching parameter" X and against each other. These results show that, for the case of a multicarrier input, an output signal-to-distortion ratio of around 25 db corresponds to a practical efficiency of around 6 per cent.

Constant-Ratio Code and Automatic-RQ on Transoceanic HF Radio Services—John B. Moore (p. 72)

Historical development of present-day commercial teleprinter services is briefly tabulated according to dates of significant advances. The 7-unit form of basic constant-ratio code is given, and its advantages explained; indicative values of improvement are tabulated. A general description of the Automatic-RQ method and system, rather than specific designs, is given. Commercial application and growth in the international services is illustrated by that of TEX (Overseas Teleprinter Exchange) service. Improvement in error probability and reliability by use of 7-unit ARQ on such services is given in terms of character-transposition probability, net channel speed in words per minute, and practical operating experience.

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Component Parts

Vol. CP-7, No. 1, March, 1960

Information for Authors (p. 1)

Who's Who in PGCP (p. 2)

Thin Ferromagnetic Films—A. C. Moore (p. 3)

This article gives an account of the work at the Royal Radar Establishment (RRE), Malvern, England, on the preparation and properties of thin ferromagnetic films. The work provides the prospect of a computer store in which a million bits would occupy less than an 18-inch cube, and which would possess a switching time faster than 20 mμsec. The store would be cheap and easily constructed.

New Impregnation for Paper Capacitors—Lorant Borsody (p. 15)

The possibility was examined of improving paper capacitors by the applications of new types of impregnants. The tests proved that the paper capacitors impregnated with the various new impregnants can be improved to such an extent that they are as good as plastic film condensers in stability, heat resistance, and temperature coefficients. In addition, paper capacitors are far smaller than plastic film dielectric capacitors.

The research work undertaken showed that one way to develop the capacitors lies in research into impregnants, especially heat-resisting casting resins.

Cyrogenics—A Survey—A. Juster and P. K. Shizume (p. 26)

This paper outlines the history of man's investigations in the field of low-temperature physics. The properties and uses of liquid helium are given, and some of the phenomena which occur at temperatures near absolute zero are noted. Techniques of low-temperature experimentation are described and some of the applications of superconducting materials discussed.

Contributors (p. 34)

Electronic Computers

Vol. EC-8, No. 4, December, 1959

The Chairman's Column—Richard O. Endres (p. 431)

Transistor Pulse Circuits for 160-MC Clock Rates—W. J. Giguere, *et al.* (p. 432)

This paper consists of two parts. Parts I, by Giguere and Jamison, discusses transistor circuits capable of regenerating 6.25-mμsec, pulses at a 160-mc bit rate. Part II, by Noll, discusses techniques for multiplexing 16 digital signals with a 10-mc clock rate into a single signal with a 160-mc clock rate.

Two methods of performing the regeneration function are presented. One method consists of dc level restoration for recognition of the signal and constant current coincident circuitry for the reconstruction of the pulses. The second method consists of operating on changes in the signal for pulse recognition and the use of a bistable circuit for pulse reconstruction. Timing in the second case is obtained by a constant current coincidence gate.

Parallel-to-serial multiplexing techniques have been developed to combine sixteen parallel 10-mc clock-rate signals into a 160-mc clock-rate pulse train. The sixteen synchronous signals are applied to sixteen AND gates along with a 10-mc narrow gate pulse. The space separations of the resulting regenerated and timed AND gate output pulses is converted to time separation with only a small amount of signal loss. This is done by injecting the pulses at sixteen equally separated points on a broadband delay line. Methods have been developed to reduce spurious responses resulting from multiple reflections on the delay line.

The current mode transistor AND gates are suitable for AND/OR functions for individual 4-mμsec logic. The multiplexer may also be used as a piece of test equipment to generate repetitive 16-bit binary words with a 10-mc frame rate.

A Note on the Number of Internal Variable Assignments for Sequential Switching Circuits—E. J. McCluskey, Jr. and S. H. Unger (p. 439)

An important step in the synthesis of sequential switching circuits is the assignment of binary variable states to represent internal states of the circuit. A formula is derived here which indicates the number of different assignments which can be made for flow tables having a given number of rows. There are only three essentially different assignments possible for a four-row table, and there are 140 for a five-row table.

Synthesis of Minimal-State Machines—Seymour Ginsburg (p. 441)

A technique is presented which yields a minimal-state machine satisfying a given set of behavioral specifications. The machine is constructed in the same manner as has commonly been done in the past in synthesizing a "primitive flow table." This contribution consists, not in describing a new method of synthesizing machines, but in showing that a particular instance of an established methods yields a minimal-state machine. It is shown that the basic synthesis technique may be slightly modified so as to be applicable to obtaining a minimal-state machine which has the stability conditions desired when working with unclocked circuits.

Arithmetic Operations for Digital Computers Using a Modified Reflected Binary Code—Harold M. Lucal (p. 449)

The reflected binary or Gray code has been used chiefly in analog-to-digital conversion devices because its code sequences, representing any two consecutive integral numbers, differ in only one digit. This paper presents a method for performing the arithmetic operations of addition, subtraction, multiplication, and division using a modified reflected binary code.

The modification for integral numbers is essentially the addition of an even parity check bit to the Gray code representation. This facilitates both the arithmetic operations and the detection of errors—in the arithmetic process as well as in transmission.

An adder using this code requires circuitry which is more complex than that of a conventional binary adder by a factor of about two or three. However, the adder can be used also for subtraction with little additional circuitry and without complementation. In applications where reliability requirements justify the extra circuitry needed for arithmetic error detection, the modified reflected binary code may compare favorably with the conventional binary.

Magnetic Fields of Square-Loop Thin Films of Oblate Spheroidal Geometry—H. Chang and A. G. Milnes (p. 458)

Thin films of Ni-Fe alloy may be prepared to be anisotropic and exhibit square-loop M-H characteristics. In films that are single-domained with flux changes involving only rotation of intrinsic magnetization controlled by cross-magnetization fields, very fast switching action can be obtained for storage and logic functions.

Problems of coupling to the flux changes and interaction in an array of such films require study of the magnetic-field distribution. In the treatment given, a circular, single-domain, thin film is represented by a very flat oblate spheroid. The field distribution outside the spheroid is found by assuming that the magnetic properties are characterized by an intrinsic magnetization M, constant in magnitude, but varies in direction depending on field and energy considerations.

Calculation of the field distribution is given for a typical film with diameter to thickness ratio of 10^5. From the regions over which field changes are most significant, conclusions are drawn as to the proper size of sensing loops and spacing to avoid interaction during switching in film arrays.

Electrodeposited Twistor and Bit Wire Components—S. J. Schwartz and J. S. Sallo (p. 465)

Electrodeposition of ferromagnetic materials on wire is a suitable way of producing magnetic storage elements. One form of this element, when placed under suitable torsional strain (*i.e.*, as a twistor), has magnetic properties suitable for memory application. Through research into the electrodeposition process, a new device has been developed which requires no external stressing. This device has been designated as the "bit wire." The materials possess the desirable temperature stability usually associated with ferromagnetic metals and exhibit a high signal-to-noise ratio.

Both linear selection and coincident current memory arrays have been constructed with bit wire and plated twistors. The switching characteristics and drive requirements are similar for both materials. The significant difference lies in the fabricating technique, since the bit wire requires no stressing. Both devices are packaged, since undesired strains can change their properties. This problem has been minimized by plating the bit wire material on semirigid wire or tubing. The tubular structure offers other advantages, since additional sense, drive, or inhibit wiring may be threaded through the tube.

Nondestructive Readout of Metallic-Tape Computer Cores—L. M. Lambert (p. 470)

The subject of this investigation is nondestructive readout of metallic-tape memory cores by the application of a magnetomotive force spatially in quadrature to the direction of remanent flux. A simple method of fabrication is proposed and empirical data for the design of the nondestructive read systems is obtained.

The use of nondestructive readout is not limited to digital computer circuits and no attempt has been made to use this method in any particular application; an experimental shift register was built, however, to test the method in a practical application. The nature of the system permits high-speed low-current-level operation in either digital or analog applications.

Diode-Steered Magnetic-Core Memory—A. Melmed and R. Shevlin (p. 474)

This paper describes techniques which take advantage of word arrangement to make possible large, high-speed magnetic-core memories at moderate cost. Economy is obtained by means of a two-coordinate selection system using diffused junction rectifiers as steering diodes. By taking advantage of the relatively slow recovery time of these rectifiers, automatic rewrite selection is obtained in a similar sense to that provided by a biased switch core. The familiar "inhibit" line is eliminated, reducing the memory array to a two-wire configuration. And finally, the customary core array geometry is rearranged to facilitate winding the digit wire as a balanced twisted-pair transmission line so as to eliminate the effect of post-write disturb.

The Design of a Large Electrostatic Memory—M. Graham, *et al.* (p. 479)

A large, high-speed random-access memory for the Brookhaven "Merlin" digital computer is described. This system employs barrier grid electrostatic storage tubes in a novel configuration yielding improved reliability. Basic design considerations are presented together with a description of circuitry and performance.

Systematic Scaling for Digital Differential Analyzers—Arthur Gill (p. 486)

The usefulness of large-capacity digital differential analyzers (DDA's) is severely hampered by the complexity of the scaling process. The scales needed for programming a DDA have to be compatible with the so-called "equilibrium," "topological," and "boundary" constraints, imposed by the construction of the analyzer and the nature of the problem at hand. Simultaneous trial-and-error satisfaction of all these constraints, to achieve optimal range and accuracy of computation, is practically impossible for any problem involving more than a few integrators. The paper shows how the scaling constraints can be organized in a matrix form, and how optimal scales can be produced in a systematic manner. The proposed scheme, which can be programmed for automatic execution, is adaptable for DDA's operating in conjunction with general-purpose digital computers.

Russian Visit to U. S. Computers—E. M. Zaitzeff and M. M. Astrahan (p. 489)

In April and May, 1959 an exchange of visits by computer experts took place between the U. S. and the U.S.S.R. This article will describe the series of negotiations which led up to this exchange and will also describe the visit of the Russian delegation to America. The visit of the U. S. delegation to Russia will be reported separately in a joint article edited by Willis Ware that will appear in the March, 1960 issue of IRE TRANSACTIONS ON ELECTRONIC COMPUTERS.

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Abstracts of Current Computer Literature (p. 507)

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Information Theory

Vol. IT-6, No. 1, March, 1960

Frontispiece—L. A. Zadeh (p. 2)

Editorial—L. A. Zadeh (p. 3)

Optimum System Theory Using a General Bayes Criterion—V. S. Pugachev (p. 4)

An extention of the general method of obtaining an optimum system developed by the author is given to include the case of nonlinear dependence of the observed function on signal parameters. The method affords effective determining of optimum systems designed for the detection and reproduction of signals in the presence of noise using various practically adequate criteria.

Quantizing for Minimum Distortion—Joel Max (p. 7)

This paper discusses the problem of the minimization of the distortion of a signal by a quantizer when the number of output levels of the quantizer is fixed. The distortion is defined as the expected value of some function of the error between the input and the output of the quantizer. Equations are derived for the parameters of a quantizer with minimum distortion. The equations are not soluble without recourse to numerical methods, so an algorithm is developed to simplify their numerical solution. The case of an input signal with normally distributed amplitude and an expected squared error distortion measure is explicitly computed and values of the optimum quantizer parameters are tabulated. The optimization of a quantizer subject to the restriction that both input and output levels be equally spaced is also treated, and appropriate parameters are tabulated for the same case as above.

A Note on *P*-nary Adjacent-Error-Correcting Codes—Bernard Elspas (p. 13)

Binary group codes described by Abramson permit the correction of all single errors and all double errors in adjacent digits, with the use of significantly fewer check digits than codes capable of correcting all double-bit errors.

This note considers the generalization of Abramson's codes to the p-nary case, where a symbol alphabet consisting of the digits $0, 1, \cdots, p-1$ is used for transmission, p being a prime number. Examples of such p-nary codes are given, as well as necessary conditions for their existence. These codes bear the same relation to the p-nary Golay codes as Abramson's codes do to the familiar Hamming codes.

Some as yet unanswered questions are raised, and suggestions for further possible generalizations are given.

Codes for the Correction of "Clustered" Errors—Siegfried H. Reiger (p. 16)

A method is described which permits the systematic construction of codes capable of error-free transmission, provided errors occur in "clusters" of limited duration. The method is valid for error clusters of any prescribed duration. The codes are relatively easy to implement and decoding operations are straightforward. Specific examples are given and applications to teletype transmission are discussed.

A Class of Codes for Signaling on a Noisy Continuous Channel—John L. Kelly, Jr. (p. 22)

A class of codes for continuous channels is described. These are block codes in which the code words can be computed from a much smaller set of generators. It is shown that codes of this type exist which will yield arbitrarily small error rates at any signaling rate below channel capacity. In fact, if the generators are chosen at random, it is shown that the expected error rate obeys a bound established by Shannon for general random codes.

A Bibliography of Information Theory (Communication Theory—Cybernetics) Third Supplement—F. Louis H. M. Stumpers (p. 25)

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Microwave Theory and Techniques

Vol. MTT-8, No. 2, March, 1960

Editorial—Harold M. Barlow (p. 131)

Broad-band Coaxial Choked Coupling Design—Howard M. King (p. 132)

Equations and curves are presented to predict the frequency bandwidth of coaxial choke couplings in terms of the choke parameters. Choke couplings discussed are those applicable to rotary joints and dc isolation units.

A Study of Multielement Transmission Lines—Hiroshi Kogo (p. 136)

Although many papers have been published on the subject of multielement transmission lines, the application to practical problems seems rather inconvenient. The author proposes a solution to the general equations which relate the voltage difference between the lines and the mesh current. Under particular conditions, it is shown that only a single type of propagating mode exists. In this case, the solution has been obtained by the so called "decomposition method," *i.e.*, assuming several virtual two element transmission lines in lieu of the existing multielement transmission line. The problem has been solved by means of the resolved superposed virtual lines taking into account the existing boundary condition.

Measurement of Relative Phase Shift at Microwave Frequencies—G. A. Finnila, *et al.* (p. 143)

A method is described for measuring the relative phase shift of microwave devices, such as traveling-wave tubes, which utilizes the serrodyne technique to transfer the measurements into the audio-frequency range. The method is used to measure the phase shift incidental to the variation of the dc potentials applied to the several electrodes of a 2- to 4-kmc traveling-wave tube. This method is particularly useful in coaxial systems, where accurately calibrated phase shifters (and attenuators without phase shift) are not available.

Resonant Modes in Waveguide Windows—M. P. Forrer and E. T. Jaynes (p. 147)

Analysis and experimental verification of a class of resonant fields, called ghost-modes, occurring in waveguide dielectric windows, are presented. Numerical solutions for a simple geometry are given through universal curves. Knowledge about ghost-modes has importance to designers of high-power windows. It also leads to a measuring technique for dielectric constants through a frequency measurement.

Temperature Compensation of Coaxial Cavities—J. R. Cogdell, *et al.* (p. 151)

This paper describes a technique for temperature compensation of coaxial cavities by controlling the capacitance between the end of the center conductor and an end plate across the outer conductor. A formula is derived for this capacitance which is verified experimentally. Supplemental design data are also obtained experimentally.

A Graphical Method for Measuring Dielectric Constants at Microwave Frequencies—Charles B. Sharpe (p. 155)

This paper describes a graphical method for measuring the real and imaginary parts of the dielectric constant $\epsilon/\epsilon_0 = \epsilon' - j\epsilon''$ of materials at microwave frequencies. The method is based on the network approach to dielectric measurements proposed by Oliner and Altschuler in which the dielectric sample fills a section of transmission line or waveguide. In contrast to their method, the network representing the dielectric sample is analyzed in terms of the bilinear transformation

$$\Gamma' = \frac{a\Gamma + b}{c\Gamma + s}; \qquad ad - bc = 4.$$

The analysis proceeds from the geometric properties of the image circle in the Γ plane obtained by terminating the output line in a calibrated sliding short.

The technique described retains the desirable features of the network approach but avoids the necessity of measuring both scattering coefficients. As a result the procedure is more direct and, in the case of the TEM configuration, leads to an entirely graphical solution in which the complex dielectric constant can be read from a Smith chart overlay.

Wide-Band Strip-Line Magic-T—E. M. T. Jones (p. 160)

This paper presents theoretical performance calculations of a novel form of wide-band strip-line Magic-T that uses two dual strip-line band-pass filters. When all four ports are terminated in the same impedance, the VSWR at each port is less than 1.47 over a 2:1 frequency band, while the isolation between opposite ports is greater than 20 db over this frequency band.

A General Theorem on an Optimum Stepped Impedance Transformer—Henry T. Riblet (p. 169)

With the assistance of a mathematical theorem demonstrated by Eaton in a companion paper, it is shown rigorously, in the limit of small impedance transformation, that the familiar binomial impedance transformer, consisting of equal quarter-wave steps, is the shortest, monotonic, maximally-flat, stepped, transmission-line transformer having steps commensurate in length with the midband guide-wavelength, and coincident zeros at the midband frequency.

It is shown how this theorem places very severe limitations on any effort to improve on the performance of a quarter-wave transformer by increasing the number of its impedance steps without a corresponding increase in its length.

Minimal Positive Polynomials—James E. Eaton (p. 171)

A proof is given of a purely mathematical theorem on the polynomial of lowest degree with positive coefficients having a prescribed root of unity as a multiple root.

H. J. Riblet has conjectured the theorem below. In the preceding paper, he applies his theorem to optimum impedance transformer design.

Complementarity in the Study of Transmission Lines—G. Owyang and R. King (p. 172)

The principle of complementarity is applied to the slot transmission line. The properties of a dual circuit are investigated. The pairs of several possible duals for a given configuration are correlated and new quantities are defined for use with different types of circuits. A complete parallelism between the two-wire line and the two-slot line is established for the ideal cases and is extended by approximation to include the practical cases.

Measurements were made with a two-slot transmission line and its associated probing system. The method of testing the line for balance is discussed. The transverse distribution of the longitudinal current and the attenuation constant were measured.

The analogy between the steady-state field in a conducting medium and the electrostatic field in a dielectric is investigated. The expressions for the constants of a two-slot line are given in a form that permits a ready evaluation from experimental data obtained with the electrolytic tank. The measured results are compared with theoretical values.

High Resolution Millimeter Wave Fabry-Perot Interferometer—William Culshaw (p. 182)

The design and operation of a microwave Fabry-Perot interferometer at wavelengths around 6 mm is described. This uses reflectors which are simple, easy to make, and which are capable of scaling for operation at short wavelengths in the ultramicrowave region. With power reflection coefficients around 0.999, very sharp fringes and Q values around 100,000 were obtained on the interferometer. Effects of diffraction in the interferometer are considered, and wavelength measurements with this particular interferometer indicate that accuracies of 0.04 per cent are obtained without any diffraction correction. Advantages of such an interferometer for ultramicrowaves are that the component parts are large compared with the wavelength, the effects of diffraction decrease with the wavelength, and the problem of maintaining a high Q with a single mode of propagation and a structure of adequate size is made much easier. Such an interferometer forms the cavity resonator for ultramicrowaves. It can thus be used for such conventional purposes as wavelength measurements, wavelength spectral analysis, dielectric constant, and loss measurements, or as the cavity resonator for frequency stabilization, or as the cavity resonator for a millimeter- or submillimeter-wavelength maser.

Boundary Conditions and Ohmic Losses in Conducting Wedges—Robin M. Chisholm (p. 189)

The present work is concerned with the boundary conditions required to calculate the ohmic losses occurring in metallic wedges under the influence of electromagnetic waves which are sinusoidal in time. The validity of the surface impedance condition used in calculating waveguide wall losses is examined carefully, and a "modified" surface impedance condition, which can be applied to wedge problems in which the perfectly conducting solution is known, is developed. A simple waveguide having a circular cross section, a sector of which is occupied by a metal wedge, is used as an example. The tangential magnetic field variations along the surface of the wedge are shown graphically, demonstrating, near the tip of the wedge, a large deviation from the tangential magnetic field of the perfectly conducting solution.

On the Theory of the Ferrite Resonance Isolator—E. Schlomann (p. 199)

The attenuation constants for both directions of propagation in a rectangular waveguide loaded with a small slab of ferrite are calculated by means of perturbation theory. The maximum attainable ratio of reverse to forward attenuation is found to be inversely proportional to the square of the bandwidth, with a constant of proportionality that is dependent on the shape of the ferrite slab and the proximity of cutoff. The figure of merit is largest for the case of a thin ferrite slab magnetized perpendicular to the plane of the slab. It is shown that a significant increase in the figure of merit can be obtained by proper use of the anisotropy of grain-oriented materials or single crystals.

Analysis of Microwave Measurement Techniques by Means of Signal Flow Graphs—J. K. Hunton (p. 206)

Microwave measurement techniques can be analyzed more simply by using signal flow graphs instead of the customary scattering matrices to describe the microwave networks used in the measuring system. This is because the flow graphs of individual networks are simply joined together when the networks are cascaded and the solution for the system can be written down by inspection of the over-all flow graph by application of the nontouching loop rule. This paper reviews the method of setting up flow graphs of microwave networks and the rule for their solution. A single directional-coupler reflectometer system for measuring the reflection coefficient of a load is then analyzed by this method. The analysis shows how auxiliary tuners can be used to cancel residual error terms in the measurement of the magnitude of the reflection coefficient at a particular frequency. The analysis also shows how an additional tuner can be used to measure the phase angle of the reflection coefficient. These reflectometer techniques are particularly useful in the measurement of very small reflections.

Stepped Transformers for Partially Filled Transmission Lines—D. J. Sullivan and D. A. Parkes (p. 212)

In recent years, partially-filled transmission lines have been used to improve the characteristics of various ferrite and garnet devices. This paper presents a generalized outline for determining the approximate effective guide wavelength and characteristic impedance of two types of (dielectric-loaded) partially-filled transmission line. The results are used to determine the geometries required for the design of optimum stepped transmission line transformers. The stepped transitions are designed to yield a Tchebycheff-type response for any given bandwidth. The measured results for stepped transitions in partially filled coaxial line and partially filled double-ridge waveguide are presented. The data are found to approximate the theory closely.

Parametric Diodes in a Maser Phase-Locked Frequency Divider—M. L. Stitch, *et al.* (p. 218)

The use of an ammonia-beam maser in a portable frequency standard requires a frequency divider which can be transistorized. A divider which uses no microwave tubes and hence one that can be transistorized is described. An ammonia-maser-controlled signal generator used to tune up the divider is also described. It is found that the use of a parametric diode frequency multiplier substantially improves the lock-in performance of the divider. Some data are given for comparing the performance of the maser frequency divider with and without the parametric diode frequency multiplier.

Parametric Devices and Masers: An Anno-

tated Bibliography—E. Mount and B. Begg (p. 222)

Correction to "Tables for Cascaded Homogeneous Quarter-Wave Transformers"—Leo Young (p. 243)

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PGMTT National Symposium Program (p. 260)

PGMTT Roster (p. 261)

Space Electronics and Telemetry

Vol. SET-6, No. 1, March, 1960

Astronomy for the Nonastronomer—Robert R. Newton (p. 1)

Kinematical observations of the solar system have attained an accuracy reached in few other areas of measurement. The adequate description of these observations requires an elaborate and accurate terminology. This paper defines and discusses most of the important terms, coordinate systems, and methods of time reckoning which are used by astronomers in describing the motion of the solar system. No previous background in astronomy on the part of the reader is required. Warning is also given concerning terms whose meanings look obvious, but which in fact do not mean what they seem to.

Energy Spectra of FM System with Low Beta, High Deviation Ratio, and MF Which Approaches Carrier Frequency—Sheldon L. Simmons (p. 17)

A technique was developed at the Naval Air Missile Test Center to determine energy spectra of an FM system which has a low Beta, a high deviation ratio, and a modulation frequency which approaches the carrier frequency. This technique may be used for analysis of any FM wave and yields theoretical results which conform closely to actual operating results.

How Environment Affects Magnetic Recording Tape—Clarence B. Stanley (p. 19)

The increasing emphasis on higher and higher operating and/or storage temperatures for data acquisition apparatus requires a critical appraisal of the behavior of available magnetic recording tapes as their rated operating limits are approached or exceeded.

Among the criteria that bear examination are the dimensional stability, strength and toughness of the substrate, and the chemical stability of the binder and the magnetic material.

Unexpected physical effects can be experienced within the generally accepted "safe" environmental limits. Critical temperatures and observed effects are described.

Threshold Improvement in an FM Subcarrier System—Benn D. Martin (p. 25)

The paper is concerned with the causes and characteristics of threshold behavior in pulse-averaging and phase-coherent ("phase-locked loop") FM subcarrier discriminators. An analytical discussion of the basic elements of each form of discriminator is first presented, leading to a comparison of the devices for input modulation indexes of one and five, in the presence of noise. For the first time in the literature, the effect of additional output filtering following the ideal phase-coherent loop is discussed. Finally, the requisite modulation characteristics for an improved threshold in a phase-locked loop discriminator are presented, followed by a brief description of the approaches which may be taken in the design of such a system.

The Astronautic Chart—Roy C. Spencer (p. 34)

The Astronautic chart is a nomograph or alignment chart so arranged that a single straight line marks off values of the velocity, mass, mean distance, period, and acceleration of any two-body orbiting system. It is illustrated with numerous examples of orbits of planets about the sun, moons about their planets, and artificial earth satellites.

All scales give correct values at the extremities of the minor diameter of the elliptical orbit. In the case of binary stars where the masses are comparable, the scales also give correct values of the *total mass*, *total separation*, *relative velocity*, and *relative acceleration*.

A Versatile PAM/PDM Decommuntation Station—J. A. Adams and W. T. Johnson (p. 38)

The growing complexity of data-handling systems and the need for less complicated and smaller decommutation devices led to the development of the PAM/PDM decommutation station shown in Fig. 1. The PAM/PDM data-handling capability of this station is 100 channels and, for the system shown, the utilized panel space is $26\frac{1}{4}$ inches.

The Navy's Portable Satellite Tracking Stations—F. M. Ashbrok and D. D. Stevenson (p. 41)

The stations described recover Doppler frequencies to an accuracy of one part in 10^9 and subcarrier oscillator frequencies to 15 kc bandwidths. Coherent phase detection and a tracking local oscillator to minimize required reception bandwidth maximizes signal sensitivity. Station portability accommodates rapid changes of location as dictated by satellite projects and the flexibility of the receiving and recording equipment due to unitized construction permits inexpensive modifications to accommodate present and future satellite programs.

Ground Antenna for Space Communication System—K. W. Linnes, *et al.* (p. 45)

The accurate tracking and telemetering of space probes requires the use of very sensitive receiving equipment and large antennas. The TRAC(E) system developed by the Jet Propulsion Laboratory utilizes an 85-foot-diameter, equatorially mounted, parabolic reflector. The antenna, similar to those used for radio astronomy, is located near Goldstone Lake near Barstow, Calif. The mechanical and electrical characteristics of the antenna and its subsystems are discussed, and its performance and the way it was used in tracking the lunar probe Pioneer IV are described. Limitations imposed on the space communication system by the ground antenna are discussed, and possible methods of improvement are listed.

Problems in Space Exploration—Robert Jastrow (p. 55)

IRIG, Inter-Range Instrumentation Group—History, Functions and Status, 1959—Beuhring W. Pike (p. 59)

The Inter-Range Instrumentation Group (IRIG) was established in 1952 by the commanders of the United States guided missile test ranges, principally for the purpose of facilitating the interchange of information on range instrumentation. Today, the IRIG consists of a Steering Committee and ten Technical Working Groups. Among other activities, the IRIG prepares and disseminates recommended standards and other documents (such as glossaries of terms and catalogs of range instruments) to advance the range instrumentation art.

Telemetry Working Group of the Inter-Range Instrumentation Group—Beuhring W. Pike (p. 61)

One of the ten Technical Working Groups of the IRIG (Inter-Range Instrumentation Group, established by the commanders of the United States guided missile test range), is the Telemetry Working Group (TWG). Among other activities, the TWG has prepared several System Standards that have been published as IRIG Recommendations.

Contributors (p. 65)

Abstracts and References

Compiled by the Radio Research Organization of the Department of Scientific and Industrial Research, London, England, and Published by Arrangement with that Department and *Electronic Technology* (incorporating *Wireless Engineer* and *Electronic and Radio Engineer*), London, England

NOTE: The Institute of Radio Engineers does not have available copies of the publications mentioned in these pages, nor does it have reprints of the articles abstracted. Correspondence regarding these articles and requests for their procurement should be addressed to the individual publications, not to the IRE.

Acoustics and Audio Frequencies...... 1197
Automatic Computers................ 1198
Circuits and Circuit Elements......... 1199
General Physics..................... 1200
Geophysical and Extraterrestrial Phenomena......................... 1201
Location and Aids to Navigation....... 1203
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The number in heavy type at the upper left of each Abstract is its Universal Decimal Classification number. The number in heavy type at the top right is the serial number of the Abstract. DC numbers marked with a dagger (†) must be regarded as provisional.

UDC NUMBERS

Certain changes and extensions in UDC numbers, as published in PE Notes up to and including PE 666, will be introduced in this and subsequent issues. The main changes are:

Artificial satellites:	551.507.362.2	(PE 657)
Semiconductor devices:	621.382	(PE 657)
Velocity-control tubes, klystrons, etc.:	621.385.6	(PE 634)
Quality of received signal, propagation conditions, etc.:	621.391.8	(PE 651)
Color television:	621.397.132	(PE 650)

The "Extensions and Corrections to the UDC," Ser. 3, No. 6, August, 1959, contains details of PE Notes 598–658. This and other UDC publications, including individual PE Notes, are obtainable from The International Federation for Documentation, Willem Witsenplein 6, The Hague, Netherlands, or from The British Standards Institution, 2 Park Street, London, W.1., England.

ACOUSTICS AND AUDIO FREQUENCIES

534.23:621.396.677.3 1463

Comparison between the Performances of a Time-Averaged Product Array and an Intraclass Correlator—D. C. Fakley. (*J. Acoust. Soc. Amer.*, vol. 31, pp. 1307–1314; October, 1959.) A 'class I' array of the type discussed by Berman and Clay (336 of 1958) operating with four receiving elements, is shown to offer no advantage over an intraclass correlator in respect of detection performance and resolving power.

A list of organizations which have available English translations of Russian journals in the electronics and allied fields appears at the end of the Abstracts and References section.

The Index to the Abstracts and References published in the PROC. IRE from February, 1959 through January, 1960 is published by the PROC. IRE, June, 1960, Part II. It is also published by *Electronic Technology* (incorporating *Wireless Engineer* and *Electronic and Radio Engineer*) and included in the April, 1960 issue of that Journal. Included with the Index is a selected list of journals scanned for abstracting with publishers' addresses.

534.232 1464

Mutual Radiation Impedance of Sources on a Sphere—C. H. Sherman. (*J. Acoust. Soc. Amer.*, vol. 31, pp. 947–952; July, 1959.) Expressions for the mutual radiation impedance coefficient are derived in the cases of uniformly vibrating circular and rectangular acoustic sources on a rigid spherical baffle.

534.26 1465

Diffraction of a Plane Sound Wave by a Semi-infinite Thin Elastic Plate—G. L. Lamb, Jr. (*J. Acoust. Soc. Amer.*, vol. 31, pp. 929–935; July, 1959.) The problem is formulated in terms of a) an integral equation, relating the discontinuity in pressure across the diffracting plate to its flexural displacement, and b) the usual fourth-order thin-plate differential equation governing the flexural motion of the plate when driven by the pressure discontinuity.

534.522.1 1466

The Effect of a Progressive Ultrasonic Wave on a Light Beam of Finite Width—K. L. Zankel. (*Naturwiss.*, vol. 46, pp. 105–106; February, 1959. In English.) Expressions are given for the application of refraction methods, such as that used by Breazeale *et al.* (3538 of 1959), to the measurement of the pressure of a sinusoidal ultrasonic wave and that of a distorted finite-amplitude wave.

534.522.1 1467

Effects of a Progressive Ultrasonic Wave on a Light Beam of Arbitrary Width—L. E. Hargrove, K. L. Zankel, and E. A. Hiedemann. (*J. Acoust. Soc. Amer.*, vol. 31, pp. 1366–1371; October, 1959.) Theoretical expressions (1466 above) are developed and compared with experimental results.

534.6:534.231 1468

Random Sound Field in Reverberation Chambers—C. G. Balachandran. (*J. Acoust. Soc. Amer.*, vol. 31, pp. 1319–1321; October, 1959.) Results are given of an experiment to compare the efficiency of different diffusing devices in the production of a completely random sound field. A rotating vane was found to be superior to other devices. A comparison of two test signals showed the superiority of random noise over a warble tone.

534.6:534.84 1469

Pulse Technique applied to Acoustical Testing—A. C. F. Cho and R. B. Watson. (*J. Acoust. Soc. Amer.*, vol. 31, pp. 1322–1326; October, 1959.) Brief description of a system in which pulses of variable length and repetition rate are transmitted on spot frequencies between 1 and 12 kc. The received signal may be gated and delayed to allow separation of direct and reflected sound pulses. Results of extensive tests made with the equipment in a large lecture hall are given.

534.614–14 1470

Transistorized Velocimeter for Measuring the Speed of Sound in the Sea—C. E. Tschiegg and E. E. Hays. (*J. Acoust. Soc. Amer.*, vol. 31, pp. 1038–1039; July, 1959.) See 1296 of 1958 (Greenspan and Tschiegg).

534.75 1471

Auditory Adaptation in Noise—H. N. Wright. (*J. Acoust. Soc. Amer.*, vol. 31, pp. 1004–1012; July, 1959.) The initial rate, extent and recovery from auditory adaptation were measured in both the presence and absence of noise in ten normal ears by the fixed-intensity method at 250, 1000 and 4000 cps.

534.76 1472

Some Measurements on the Effects of Interchannel Intensity and Time Differences in Two-Channel Sound Systems—D. M. Leakey. (*J. Acoust. Soc. Amer.*, vol. 31, pp. 977–986; July, 1959.) A theory is developed based on the assumption that the brain is sensitive to interaural time difference and its variation with head movement. This is in reasonable agreement with practical results.

534.78 1473

Effect of Sample Duration on the Articulation of Sounds in Normal and Clipped Speech—R. Ahmend and R. Fatehchand. (*J. Acoust. Soc. Amer.*, vol. 31, pp. 1022–1029; July, 1959.) Whether or not vowels are clipped, their segment lengths can be considerably reduced with little effect on articulation. This does not hold for consonants, with the exception of unclipped semivowels. The high articulation of interrupted speech is discussed and some results are given.

534.79 1474

On the Validity of the Loudness Scale—S. S. Stevens. (*J. Acoust. Soc. Amer.*, vol. 31, pp. 995–1003; July, 1959.) Objections to the sone scale are considered and it is shown how the form of the scale may be verified by cross-modality matchings.

534.84:061.3 1475

International Convention on Architectural and Room Acoustics—(*Hochfrequenz. und Elektroak.*, vol. 67, pp. 97–168; January, 1959.) The text is given of 15 out of 40 papers presented at a convention held in Dresden, September 5–8, 1957.

534.844 1476
Sabine Reverberation Equation and Sound Power Calculations—R. W. Young. (*J. Acoust. Soc. Amer.*, vol. 31, pp. 912–921; July, 1959.) A review of sound power and decay formulas and an assessment of their practical use. The Sabine reverberation equation, given a certain interpretation, is found to be the most suitable for general engineering purposes.

534.846 1477
Acoustoelectronic Auditorium—H. F. Olson. (*J. Acoust. Soc. Amer.*, vol. 31, pp. 872–879; July, 1959.) Description of the design of an auditorium and sound reinforcement apparatus as an integrated system.

534.88 1478
Use of Pressure-Gradient Receivers in a Correlator Receiving System—M. J. Jacobson and R. J. Talham. (*J. Acoust. Soc. Amer.*, vol. 31, pp. 1352–1362; October, 1959.) Theoretical analysis of a steerable correlator receiving system containing two directional receivers. The computer signal-to-noise ratio at the output is compared with that of a system containing two omnidirectional receivers.

534.88 1479
Hydrophone Minor Lobes produced by Volume Scattering—T. G. Bell. (*J. Acoust. Soc. Amer.*, vol. 31, pp. 1304–1307; October, 1959.) A method is given for calculating approximately the minor-lobe response of a directional hydrophone due to volume scattering.

534.88:534.232.089.6 1480
Pressure Phone for Hydrophone Calibrations—C. C. Sims and R. J. Bobber (*J. Acoust. Soc. Amer.*, vol. 31, pp. 1315–1318; October, 1959.) A small closed system for the absolute calibration of a standard hydrophone at frequencies up to 5 kc is described.

621.395.623.7.001.4:534.76 1481
Evaluation of a Stereophonic Loudspeaker by Multiple Microphone Arrays—R. W. Carlisle and A. Schwartz. (*J. Acoust. Soc. Amer.*, vol. 31, pp. 1348–1351; October, 1959.) A system is described for measuring the effective frequency response of a stereophonic loudspeaker arrangement in a live room. The method is shown to be superior to the anechoic-chamber method at low frequencies.

621.395.623.742 1482
A Method of Mechanical Damping of Dynamic Loudspeakers by Porous Materials—L. Keibs. (*Tech. Mitt. BRF, Berlin*, vol. 3, pp. 7–12; October, 1959.) Design theory regarding the damping of loudspeaker cones to eliminate self-resonances is given, and a method of measurement of damping effects is outlined.

621.395.625.3 1483
Improving the Dynamic Range of Tape Recording—L. H. Bedford. (*Wireless World*, vol. 66, pp. 104–106; March, 1960.) Compensation for manual compression of the input signal using a pilot tone outside the AF range.

621.395.625.3:538.221 1484
Particle Interaction in Magnetic Recording Tapes—Woodward and Dellatorre. (*See* 1723.)

621.395.625.3:681.846.7 1485
The Transport Mechanism of the Magnetic-Tape Recorder for Reporters—O. W. Meier. (*Tech. Mitt. BRF, Berlin*, vol. 3, pp. 12–21; October, 1959.) Details are given of a battery-operated portable tape recorder used by the East German broadcasting authorities. A comparative table is included of the mechanical specifications for nine types of portable recorder of European manufacture.

621.395.625.3:681.846.7 1486
The Transistor Amplifier of the Magnetic-Tape Recorder Type R20 for Reporting—A. Tolk. (*Tech. Mitt. BRF, Berlin*, vol. 3, pp. 21–25; October, 1959.) Circuit and performance details of a battery-operated recorder are given. See 1485 above.

621.315.212 1487
Reflection Coefficient Curves of Compensated Discontinuities on Coaxial Lines and the Determination of the Optimum Dimensions—A. Kraus. (*J. Brit. IRE*, vol. 20, pp. 137–152; February, 1960.)

621.315.687.029.6+621.372.855 1488
Microwave Terminations—G. Bostick. (*Electronics*, vol. 33, pp. 50–51; January 8, 1960.) Characteristics and relative costs of the four major classes of coaxial-cable and waveguide terminations.

621.372.2:621.372.51 1489
100:1 Bandwidth Balun Transformer—J. W. Duncan and V. P. Minerva. (PROC. IRE, vol. 48, pp. 156–164; February, 1960.) The design theory is given for a balun made by cutting away the outside wall of a coaxial cable. The input reflection coefficient gives a Tchebycheff response in the pass band. The measured voltage SWR did not exceed 1.25:1 over a 50:1 bandwidth and the dissipation loss was less than 0.1 db over most of the range.

621.372.2.012.11 1490
The Smith Chart: Part 3—Matching Transmission Lines to Aerials and Uses of Stubs—R. A. Hickson. (*Wireless World*, vol. 66, pp. 141–146; March, 1960.) Considers various matching elements with detailed examples. Parts 1 and 2: 749 of March.

621.372.8 1491
TM Waves in Submillimetric Region—C. A. Martin and A. E. Karbowiak. (PROC. IRE, vol. 48, pp. 250–251; February, 1960.) Discussion of 13 of 1959 (Karbowiak) with author's comment. The attenuation characteristics for certain modes of circular waveguide are shown to increase indefinitely with frequency and not to follow an $f^{-5/2}$ law as suggested earlier.

621.372.8:621.385.63 1492
A Class of Waveguide-Coupled Slow-Wave Structures—J. Feinstein and R. J. Collier. (IRE TRANS. ON ELECTRON DEVICES, vol. ED-6, pp. 9–17; January, 1959. Abstract, PROC. IRE, vol. 47, p. 611; April, 1959.)

621.372.823:621.372.852.5 1493
Round Waveguide with Double Lining—H. G. Unger. (*Bell Sys. Tech. J.*, vol. 39, pp. 161–167; January, 1960.) A mathematical analysis of the effects of thin base layers of low-loss material at bends indicates a reduction of the TE_{01} loss, and mode filtering.

621.372.825 1494
Surface Resistance of Corrugated Conductors—T. Hosono. (PROC. IRE, vol. 48, p. 247; February, 1960.) The average surface resistance is shown to be more than that of a plain surface, indicating that losses may be less in plain circular waveguide than in those made from spaced disks. This reverses an earlier conclusion [see *Proc. IEE*, Part B, vol. 106, supplement pp. 37–46 (Gent); 1959].

621.372.85 1495
Evanescent Modes in a Partially Filled Gyromagnetic Rectangular Waveguide—C. T. Tai. (*J. Appl. Phys.*, vol. 31, pp. 220–221; January, 1960.) A demonstration of the existence of these modes, based on the asymptotic form of the characteristic equation.

621.396.67:621.315.1:621.391.812.63.029.45 1496
A Very-Low-Frequency Antenna for Investigating the Ionosphere with Horizontally Polarized Radio Waves—R. S. Macmillan, W. V. T. Rusch, and R. M. Golden. (*J. Res. Nat. Bur. Stand.*, vol. 64D, pp. 27–35; January/February, 1960.) The radiation characteristics of resonant horizontal $\lambda/2$ dipoles have been verified experimentally and the effects of ground conductivity investigated. The loading of an existing power transmission line to convert a section of it into a dipole is described. See also 1672 of 1959 (Golden *et al.*).

621.396.674.095(204) 1497
Basic Experimental Studies of the Magnetic Field from Electromagnetic Sources Immersed in a Semi-infinite Conducting Medium—M. B. Kraichman. (*J. Res. Nat. Bur. Stand.*, vol. 64D, pp. 21–25; January/February, 1960.) Measurements have been made of the magnetic field in air due to different dipoles and loops energized at 296 kc and immersed in a tank containing a sodium chloride solution.

621.396.677 1498
Effect of Antenna Size on Gain, Bandwidth, and Efficiency—R. F. Harrington. (*J. Res. Nat. Bur. Stand.*, vol. 64D, pp. 1–12; January/February, 1960.) A theoretical analysis in which both near-zone and far-zone directive gains are considered. The maximum gain for a wide-band antenna is approximately that of the uniformly illuminated aperture. Higher gain can only be obtained if the antenna is a narrow-band device. For large antennas the input impedance is highly frequency-sensitive and no significant gain over a uniformly illuminated aperture is possible.

621.396.677:523.164 1499
Resolving Power of Three Antenna Patterns Derived from the Same Aperture—A. E. Covington and G. A. Harvey. (*Canad. J. Phys.*, vol. 37, pp. 1216–1229; November, 1959.) An analysis is made of the problem of deducing the spatial distribution of RF energy in an astronomical source which is smaller than the beamwidth of the antenna. The antenna pattern is represented by a series of Fourier components, and the problem is then similar to those met in the design of filters. Particular cases studied are a) a pair of equally intense point sources, and b) a uniformly bright line.

621.396.677.3:534.23 1500
Comparison between the Performances of a Time-Averaged Product Array and an Intraclass Correlator—Fakley. (*See* 1463.)

621.396.677.7:621.372.826 1501
Surface-Wave Resonance Effect in a Reactive Cylindrical Structure Excited by an Axial Line Source—A. L. Cullen. (*J. Res. Nat. Bur. Stand.*, vol. 64D, pp. 13–19; January/February, 1960.) The existence of strong resonance phenomena has been established theoretically. In a particular example, only 1.1 per cent of the power delivered to the line source is radiated in unwanted modes. The distance of the source from the cylinder does not affect the result in a first-order approximation.

621.396.677.73:621.391.812.62.029.64 1502
Over-Sea Propagation of Microwaves and Anti-reflected-Wave Antenna—Kawazu, Kato and Morita. (*See* 1754.)

AUTOMATIC COMPUTERS

681.142:061.3 1503
Computers head for 1000-MC/s Operation—T. Maguire. (*Electronics*, vol. 33, pp. 55–59; January 29, 1960.) Report of recent develop-

ments in phase-locked oscillators, tunnel diodes and cross-film cryotrons, based on papers presented at the Computer Conference, Boston, Mass. December 1–3, 1959.

681.142:537.312.62 1504
Low-Temperature Storage Elements—E. H. Rhoderick. (*J. Brit. IRE*, vol. 20, pp. 37–40; January, 1960.) Very high speeds and compactness are features of the Crowe cell in which a persistent current is set up around an aperture in a thin superconducting film.

621.142:621.374.3 1505
Pulse-Height-to-Digital Signal Converter—W. W. Grannemann, C. D. Longerot, R. D. Jones, D. Endsley, T. Summers, T. Lommasson, A. Pope, and D. Smith. (*Electronics*, vol. 33, pp. 58–60; January 8, 1960.) A transistorized analog/digital converter provides 7-digit binary outputs for an input of 0–2 volts at a maximum sampling rate of 13,000 pulses /sec.

681.142:621.374.5:534–8 1506
Supersonic Delay-Line Memory Device for Parametron Signal—S. Yamada and K. Kuri. (*Rep. Elec. Commun. Lab., Japan*, vol. 7, pp. 167–169; May, 1959.) Results obtained with an experimental 0.5-mm-diameter brass-wire delay line are given. Suitable coupling circuits are shown.

681.142:621.395.625.3 1507
Factors Influencing the Applications of Magnetic Tape Recording to Digital Computers—D. P. Franklin. (*J. Brit. IRE*, vol. 20, pp. 9–21; January, 1960.)

681.142:621.395.625.3 1508
A Magnetic-Disk, Random-Access Memory—A. C. Glover. (*J. Brit. IRE*, vol. 20, pp. 22–24; January, 1960.) 5×10^5 alphanumeric characters can be stored with average access time 0.5 second.

681.142:621.395.625.3 1509
Magnetic-Film File for Computer Storage—A. St. Johnston. (*J. Brit. IRE*, vol. 20, pp. 25–30; January, 1960.) A 35-mm oxide-coated film store is described in which the pickup head is not in contact with the oxide. The high-quality backing medium gives complete freedom from drop-outs.

681.142:621.395.625.3 1510
High-Speed Digital Storage using Cylindrical Magnetic Films—G. R. Hoffman, J. A. Turner, and T. Kilburn. (*J. Brit. IRE*, vol. 20, pp. 31–36; January, 1960.) Digital stores consisting of closed magnetic circuits deposited on long glass tubes are described.

681.142:621.395.625.3 1511
A High-Density File Drum as a Computer Store—L. Knight and M. P. Circuit. (*J. Brit. IRE*, vol. 20, pp. 41–45; January, 1960.) A packing density of 1000 bits/inch has been obtained using specially designed heads floating on an oil film which automatically maintains a head/track spacing of 0.002 inch.

CIRCUITS AND CIRCUIT ELEMENTS

621.318.4 1512
Analysis of Quality Factor of Annular-Core Inductors—V. E. Legg. (*Bell Sys. Tech. J.*, vol. 39, pp. 105–126; January, 1960.) A summary of formulas used to determine Q factor is supplemented with a discussion of optimum design procedures. In particular, eddy currents and dielectric losses, and the effects of distributed capacitance are considered.

621.318.57 1513
The Ferreed—a New Switching Device—A. Feiner, C. A. Lovell, T. N. Lowry, and P. G. Ridinger. (*Bell Sys. Tech. J.*, vol. 39, pp. 1–30; January, 1960.) Properties of a magnetic-reed switch responsive to the resonant field of a ferrite are considered. Switching times are in the microsecond range and dual winding facilitates coincident-pulse control. The application to switching arrays is discussed.

621.318.57:621.372.44 1514
Binocular-Type Parametron—K. Fukui, M. Shindo, T. Kurata, and K. Habara. (*Rep. Elect. Commun. Lab., Japan*, vol. 7, pp. 152–166; May, 1959.) The method of manufacture and characteristics of a parametron with a new type of ferrite core comprising a segmented disk with two apertures are described. Power consumption is about one quarter that of the toroidal-core type [410 of February (Hanawa and Kusunoki)].

621.318.57:621.382.23 1515
Microwave Switching with Computer Diodes—M. Bloom. (*Electronics*, vol. 33, pp. 85–87; January 15, 1960.) Characteristics are given of single- and double-throw Ge junction-diode switches. Satisfactory tests have been made on a coaxial switch at 1 watt and an X-band waveguide switch at 4 watts RF power.

621.319.4:621.317.7 1516
An Oscillating Capacitor of High Stability—M. von Ardenne and E. Klar. (*Nachrichtentech. Z.*, vol. 9, pp. 26–28; January, 1959.) The precision unit described is designed for use with high-resistance dc or direct-voltage measuring equipment where high stability is required. Currents of 10^{-15}–10^{-16} ampere were detected with an input resistance of $10^{13}\Omega$.

621.372:621.3.092 1517
Certain Asymptotic Relations between Frequency and Time Functions—H. Dobesch. (*Nachrichtentech. Z.*, vol. 9, pp. 13–18; January, 1959.) The relations are considered with reference to networks to which a transient is applied, and including the effect of group delay.

621.372.5 1518
Linear Network Synthesis—O. C. Bown. (*Electronic Tech.*, vol. 37, pp. 122–126; March, 1960.) "The rational fraction approximation is obtained directly in terms of the pole-zero locations in the p-plane by a process of successive approximation. The method differs from other known successive approximation techniques in being purely graphical apart from a final numerical relaxation process. A simple step-by-step account is given of the practical procedure."

621.372.54:621.398 1519
Low-Pass Filter for Subaudio Frequencies—R. C. Onstad. (*Electronics*, vol. 33, pp. 88–90; January 15, 1960.) Details are given of a low-pass RC filter suitable for use in a missile-borne telemetry system. The filter incorporates a transistor feedback amplifier and has a flat response from dc to 0.7 cps and an attenuation slope of 15 db per octave.

621.372.6 1520
Immittance Properties of Nonreciprocal Networks—A. W. Keen. (PROC. IRE, vol. 48, pp. 248–250; February, 1960.) Certain known networks are described in terms of the unitor, a nonreciprocal circuit element. These include the Batt-Duffin immittance synthesizing cycle, impedance inversion and conversion circuits and the symmetrical lattice network. See 2871 of 1959.

621.372.632:621.375.132 1521
Negative Feedback in Frequency-Changers—D. G. Tucker. (*Electronic Tech.*, vol. 37, pp. 96–98; March, 1960.) Two different forms of negative feedback are discussed; one has only passive elements in the feedback path [2018 of 1952 (Boggs)] and the other has an active element with characteristics identical to those of the forward path (297 of 1950). Their application to frequency changers is considered with reference to gain stability.

621.373 1522
The Quality of Oscillators with Differently Located Losses—W. Herzog. (*Nachrichtentech. Z.*, vol. 12, pp. 21–28; January, 1959.) A Π-network oscillator with parallel and series losses is investigated to determine whether the Q-factor can be improved by a reduction of load impedance in conjunction with an appropriate increase in oscillator gain. The reduction of load impedance is effected by considering the loss impedance to be added in parallel with the load.

621.373.4:621.376.32 1523
A Voltage-Tuned Resistance-Capacitance Oscillator—W. D. Ryan and F. E. Hetherington. (*Electronic Engrg*, vol. 32, pp. 108–110; February, 1960.) A circuit is given for an AF oscillator whose frequency of oscillation is dependent on an applied dc potential by virtue of the variable capacitance of selenium dry-disk rectifiers with reverse bias. The characteristics of suitable rectifiers are discussed.

621.373.44:621.373.2 1524
The Generation of Short High-Power Pulses by means of Spark-Gap Switches—G. Sahner. (*Nachrichtentech. Z.*, vol. 8, pp. 36–43 and 558–566; January and December, 1959.) The characteristics of the discharge current in spark-gap circuits are calculated. Tests were made on a triggered pulse-generator circuit comprising two series-connected spark gaps; equipment used and results obtained are described.

621.373.51:621.372.44 1525
Parametric Oscillations with Point-Contact Diodes at Frequencies Higher than Pumping Frequency—L. U. Kibler. (PROC. IRE, vol. 48, pp. 239–240; February, 1960.) The signal and idler frequencies are symmetrically placed with respect to a multiple of the pumping frequency. The results are consistent with the Manley-Rowe relations (see *e.g.* 773 of March).

621.373.52.029.62 1526
Designing High-Power Transistor Oscillators—W. E. Roach. (*Electronics*, vol. 33, pp. 52–55; January 8, 1960.) A step-by-step procedure is given for the design of oscillators for operation at frequencies up to 300 mc.

621.374.32:621.385.63:621.373.43 1527
A High-Speed Binary Counter based on Frequency Script Techniques—V. Met. (PROC. IRE, vol. 48, pp. 243–244; February, 1960.) An extension of previous experimental investigations into bistable oscillators (3428 of 1957).

621.374.32:621.385.832 1528
Fast Counting Circuits using E1T Tubes—V. Radeka. (*Electronic Engrg.*, vol. 32, pp. 92–95; February, 1960.) A theoretical investigation into the use of Type E1T counter tubes [3614 of 1952 (Jonker *et al.*)] at pulse repetition frequencies up to 1 mc, together with a practical design of circuit.

621.374.4 1529
Efficient Harmonic Generation—G. F. Montgomery. (PROC. IRE, vol. 48, pp. 251–252; February, 1960.) Practical harmonic generators are reviewed briefly and the most efficient is shown to be the rectifier-amplifier type. A transistor amplifier provides best efficiency at low powers.

621.374.42 1530
A Stabilized Locked-Oscillator Frequency Divider—P. R. Scott, Jr. (PROC. IRE, vol. 48,

pp. 192–200; Feburary, 1960.) The results of an analysis of the divider are presented in a graphical form suitable for design purposes.

621.375.133:621.391.822 1531

Negative-Capacitance Amplifier Noise—M. Robinson and J. Weinmann. (*Electronic Tech.*, vol. 37, pp. 127–129; March, 1960.) "The inherent limitations of negative-capacitance feedback, due to the finite time constant and internal noise of an actual amplifier, are discussed. It is shown that the limitation, caused by noise, applies to any circuit that is designed to reduce the input RC time constant."

621.375.9:538.569.4 1532

Ferromagnetic Amplifiers—A. F. H. Thomson. (Proc. IRE, vol. 48, pp. 259; February, 1960.) Note on an absorption of microwave power observed with a magnetized Y-Fe garnet sphere in a microwave field at a frequency approximately twice that corresponding to the magnetization.

621.375.9:538.569.4 1533

Maser Behaviour: Temperature and Concentration Effects—T. H. Maiman. (*J. Appl. Phys.*, vol. 31, pp. 222–223; January, 1960.) Maser action has been achieved with ruby at temperatures up to 195°K; results are given for operation at 77°K.

621.375.9:538.569.4 1534

A Tunable X-Band Ruby Maser—P. D. Gianino and F. J. Dominick. (Proc. IRE, vol. 48, p. 260; February, 1960.) Performance figures and details of simplified tuning arrangements are given.

621.375.9:621.372.44 1535

The Parametric Amplifier—C. R. Russell. (*Brit. Commun. Electronics*, vol. 7, pp. 94–98 and 190-194; February and March, 1960.) The mode of operation of parametric devices is explained and general features of semiconductor-diode, ferrite and beam-type amplifiers are discussed.

621.375.9:621.372.44 1536

Noise Consideration of the Variable-Capacitance Parametric Amplifier—M. Uenohara. (Proc. IRE, vol. 48, pp. 169–179; February, 1960.) A simplified theory, assuming the noise source is a resistance in series with the variable capacitance, gives calculated gain and noise figures agreeing with measured values for Si, Ge, and GaAs diodes.

621.375.9:621.372.44:621.385.6 1537

Some Possible Causes of Noise in Adler Tubes—Lea-Wilson: Adler, Hrbek, and Wade. (*See* 1834.)

621.376.32:621.382 1538

Wide-Band F.M. with Capacitance Diodes—C. Arsem. (*Electronics*, vol. 32, pp. 112–113; December 4, 1959.) Two circuits are described using voltage-variable capacitors to modulate a tube oscillator.

GENERAL PHYSICS

530.145:061.3 1539

Mathematical Problems of the Quantum Theory of Particles and Fields—(*Nuovo Cim.*, vol. 14, supplement pp. 1–211; 1959.) The text is given in English of 12 papers presented at an international course held at Varenna, July 21–August 9, 1958.

537.214 1540

Approximation Formulae for the Electrostatic Energy of a Space Charge—O. Emersleben. (*Naturwiss.*, vol. 46, pp. 64–65; January, 1959.) An asymptotic approximation for the es potential is derived which does not contain terms denoting the number and magnitude of the individual charges making up a space-charge cloud.

537.214:537.226 1541

The Electromagnetic Energy Stored in a Dispersive Medium—T. Hosono and T. Ohira. (Proc. IRE, vol. 48, pp. 247–248; February, 1960.) An expression for energy is derived by treating the dielectric as a two-terminal network having a frequency-dependent admittance.

537.311.1 1542

Damping Method in the Theory of Electrical Conductivity—R. Zigenlaub. (*Fiz. Tverdogo Tela*, vol. 1, pp. 1053–1061; July, 1959.) A method is suggested for calculating the conductivity tensor similar to the "time-fluctuation" method used in quantum field theory.

537.311.33 1543

A More Precise Theory of Plasma Recombination—V. L. Bonch-Bruevich. (*Fiz. Tverdogo Tela*, vol. 1, pp. 1076–1083; July, 1959.) Recombination coefficients are derived for two models: deep traps and third- and fifth-group impurity traps in Ge and Si.

537.311.33 1544

Theory of the Method of Thermal Conductivity Measurement Proposed by A. V. Ioffe and A. F. Ioffe—M. A. Kaganov. (*Zh. tekh. Fiz.*, vol. 28, pp. 2364–2367; November, 1958.) See 1661 below.

537.525 1545

Build-Up of a Discharge in Argon—M. Menes. (*Phys. Rev.*, vol. 116, pp. 481–486; November 1, 1959.) Measurements of the rate of build-up at pressures of 5–60 cm Hg, and theoretical interpretation of results.

537.533:621.385.6 1546

Time-Dependent Electron Flow—M. C. Pease. (*J. Appl. Phys.*, vol. 31, pp. 70–76; January, 1960.) General relations are given, from which a single-vector differential equation can be deduced which determines all possible solutions in the case of a constant uniform magnetic field. The application of certain time-varient solutions of this equation to anomalous behavior in various magnetron-type devices is considered.

537.533.74 1547

Double Scattering of Electrons with a Dipole Moment—M. H. Zaidi. (*Phys. Rev.*, vol. 116, pp. 241–243; October 15, 1959.) Quantum-mechanical analysis of the case where magnetic and electric fields are present between the two targets gives the same results as are obtained by treating the electrons as classical spinning tops with magnetic moments and classical electric dipoles.

537.533.79:538.221 1548

Interaction between Electron Beam and Magnet—S. Yamaguchi. (*Nuovo Cim.*, vol. 14, pp. 248–249; October 1, 1959. In English.) The diffraction effect noted when an electron beam grazes a sharp edge of a magnet (about 2000 Å thick) is described and interpreted. See 3636 of 1959.

537.533.8 1549

The Time Constant of Secondary Emission—H. W. Streitwolf and W. Brauer. (*Z. Naturforsch.*, vol. 13a, pp. 700–701; August, 1958.) See also 1178 of April (Streitwolf).

537.56 1550

Transport Phenomena in Slightly Ionized Gases: Low Electric Fields—M. S. Sodha. (*Phys. Rev.*, vol. 116, pp. 486–488; November 1, 1959.) Calculation of transport properties, in the presence of a magnetic field. For low electric fields E the results can be expressed as linear functions of E^2.

537.56 1551

Asymmetrical Triple-Probe Method for Determining Energy Distribution of Electron in Plasma—T. Okuda and K. Yamamoto. (*J. Appl. Phys.*, vol. 31, pp. 158–162; January, 1960.) The method is an improvement on one previously given [2687 of 1956 (Yamamoto and Okuda)]. A much greater range of electron energies can be examined and it can be used in electrodeless discharges.

537.56:537.29 1552

Action of a D. C. Electric Field on a Plasma: Establishment of the Equation giving the Distribution Function—A. Brin, J. L. Delcroix, and Y. Ozias. (*Compt. rend. acad. sci., Paris*, vol. 249, pp. 1093–1095; September 28, 1959.

537.56:538.56 1553

Excitation of Oscillations in a Plasma Layer—M. Sumi. (*J. Phys. Soc. Japan*, vol. 14, pp. 1093–1097; August, 1959.) Application of theory developed earlier (1513 and 2534 of 1959) to the excitation of standing waves in a uniform plasma.

537.56:538.56 1554

Oscillations of a Cylindrical Cavity in a Completely Ionized Plasma—L. M. Kovrizhnykh. (*Zh. Eksp. Teor. Fiz.*, vol. 36, pp. 839–841; March, 1959.) Investigation of the oscillations of a cylindrical cavity in a perfectly conducting plasma with applied magnetic field. The system is shown to be stable and under certain conditions waves cannot propagate along the cavity.

537.56:551.510.5 1555

Sealed-Room Experiments on the Equilibrium of Ionization in Air—O. C. Jones, R. S. Maddever, and J. H. Sanders. (*J. Atmos. Terr. Phys.*, vol. 17, pp. 134–144; December, 1959.) An attempt to determine the correct form of the equation by making measurements of as many of the quanitities appearing in the equation as possible.

538.221:537.312.62 1556

Possible Explanation of the "Coexistence" of Ferromagnetism and Superconductivity—B. T. Matthias and H. Suhl. (*Phys. Rev. Lett.*, vol. 4, pp. 51–52; January 15, 1960.) A discussion based on the suggestion that superconducting regions extend only through the thicknesses of the ferromagnetic domain walls.

538.3 1557

Electromagnetic Energy/Momentum Tensor in the Presence of Charged Matter—S. Mavridés. (*Compt. rend. acad. sci., Paris*, vol. 249, pp. 637–639; August 3, 1959.)

538.3:512.99 1558

The Method of Combinative Numbers (Nombres Combinatifs) in the Study of Electromagnetic Fields—M. P. Zlatev. (*Onde élect.*, vol. 39, pp. 908–912; December, 1959.) Maxwell's field equations and Poynting's theorem are given in group-number form. The method is proposed for problems where the use of complex numbers would give an ambiguous result.

538.561:537.56 1559

Radiation from a Current-Carrying Ring which Moves Uniformly in a Plasma Located in a Magnetic Field—L. S. Bogdankevich. (*Zh. Eksp. Teor. Fiz.*, vol. 36, pp. 835–838; March, 1959.) Estimation of losses due to Vavilov-Cherenkov radiation for a current-carrying ring which moves uniformly in a plasma perpendicular to its plane and parallel to an external magnetic field.

538.561:539.12:523.165 1560

Radiation from High-Speed Particles—P. A. Cherenkov. (*Science*, vol. 131, pp. 136–142; January 15, 1950.) Translation of Nobel Prize lecture. See also 824 of March.

538.561:539.12:537.56 1561

General Characteristics of Vavilov-Cherenkov Radiation—I. E. Tamm. (*Science*, vol. 131, pp. 206–210; January 22, 1960.) The application of the theory of Cherenkov radiation to problems of plasma physics is considered.

538.566+534.2 1562

The Exactness of the Solution of a Radiation or Diffraction Problem—P. Poincelot. (*Compt. rend. acad. sci., Paris*, vol. 249, pp. 950–951; September 7, 1959.) Criteria of uniqueness may be applied to various problems of propagation in media satisfying linear equations. See also 3628 of 1959.

538.566:535.42 1563

Diffraction of a Plane Electromagnetic Wave by a Perfectly Conducting Paraboloid of Rotation—V. A. Fok and A. A. Fedorov. (*Zh. Tekh. Fiz.*, vol. 28, pp. 2548–2566; November, 1958.) Exact solution for arbitrary angle of incidence and polarization. Asymptotic formulas for the surface current distribution are derived for wavelengths small compared with the focal length of the paraboloid.

538.566:535.42 1564

Approximate Calculations of the Diffraction of Plane Electromagnetic Waves by some Metallic Bodies: Part 2—P. Ya. Ufimtsev. (*Zh. Tekh. Fiz.*, vol. 28, pp. 2604–2616; November, 1958.) Application of the approximate method described in Part 1 (2711 of 1958) to diffraction of a plane EM wave by a perfectly conducting disk or cylinder. Results are shown graphically and compared with experimental data.

538.566:535.43 1565

Scattering by Nonspherical Particles—J. M. Greenberg. (*J. Appl. Phys.*, vol. 31, pp. 82–84; January, 1960.) "The small-angle scattering approximation of Schiff (see 1408 of 1957) is applied to several nonspherical body shapes. Effects of orientation and elongation are discussed."

538.569.4:621.391.883.2 1566

Signal-to-Noise Ratio in Nuclear Magnetic Resonance—R. Chidambaram. (*Proc. Phys. Soc.*, vol. 75, pp. 163–164; January, 1960.) The amplifier noise is expressed in terms of an equivalent input grid resistance rather than in terms of a noise figure.

538.569.4.029.6:536.46 1567

Absorption and Dispersion of Microwaves in Flames—J. Schneider and F. W. Hofmann. (*Phys. Rev.*, vol. 116, pp. 244–249; October 15, 1959.) The dependence of the high-frequency electric conductivity and the optical constants of a weakly ionized gas on the microwave frequency, the electron-molecule collision frequency, the electron concentration and an external magnetic field are discussed.

539.2:537.311.33 1568

The Influence of Lattice Vibrations on Energy and Lifetime of the Exciton—H. Haken. (*Z. Phys.*, vol. 155, pp. 223–246; May 22, 1959.) The exciton is treated as a system of two particles with Coulomb-potential interaction which are coupled to the quantized field of lattice vibrations.

539.2:548.0 1569

New Method for Calculating Wave Functions in Crystals and Molecules—J. C. Phillips and L. Kleinman. (*Phys. Rev.*, vol. 116, pp. 287–294; October 15, 1959.) Advantage is taken of crystal symmetry to construct wave functions which are best described as the smooth part of symmetrized Bloch functions.

GEOPHYSICAL AND EXTRATERRESTRIAL PHENOMENA

523.164:621.396.677 1570

Interferometer using Two Aerials with Variable Spacing at the Nançay Radio-Astronomy Station—J. Lequeux, É. Le Roux, and M. Vinokur. (*Compt. rend. acad. sci., Paris*, vol. 249, pp. 634–636; August 3, 1959.) Radiation at 21 cm λ is received by two parabolic reflectors which can be moved along a track 1500 meters long running E–W; a second track 400 meters long runs N–S. A 53.7-mc signal from a common local oscillator is transmitted by coaxial cables to the antenna sites, multiplied and mixed with the received signals. Resulting 30-mc signals are conveyed via the same cables to a correlator/detector. Results obtained with the apparatus are shown.

523.164:621.396.677 1571

Resolving Power of Three Antenna Patterns Derived from the Same Aperture—Covington and Harvey. (*See* 1499.)

523.164.32 1572

Absorption, Refraction and Scintillation Measurements at 4700 Mc/s with a Travelling-Wave-Tube Radiometer—J. P. Castelli, J. Aarons, C. Ferioli, and J. Casey. (*Planet. Space Sci.*, vol. 1, pp. 50–56; January, 1959.) A report of measurements of solar RF radiation at sunrise during July 1957, with a note on the equipment used. This consisted of a Dicke-type radiometer, a tuned-RF receiver and a 6-foot parabola antenna on an altazimuth mount.

523.164.32:523.75 1573

The Correlation of Bursts of Solar Radio Emission in the Centimetre Range with Flares and Sudden Ionospheric Distriburbances—O. Hachenberg and A. Krüger. (*J. Atmos. Terr. Phys.*, vol. 17, pp. 20–33; December, 1959.) Statistical investigations of observations during the first six months of the I.G.Y. reveal a close correlation between bursts in the cm-λ range and S.I.D.'s. It is concluded that both the cm-λ radiation and the ionizing radiation responsible for S.I.D.'s are generated by superthermal electrons.

523.165 1574

Sudden Increase of Cosmic-Ray Intensity—H. R. Anderson. (*Phys. Rev.*, vol. 116, pp. 461–462; October 15, 1959.) Report on simultaneous observations in U.S.A. and New Zealand which are not in accord with simple solar impact-zone theory.

523.165 1575

Primary Heavy Cosmic Rays near the Geomagnetic Equator—O. B. Young and F. W. Zurheide. (*Nuovo. Cim.*, vol. 14, pp. 90–98; October 1, 1959. In English). Results are given of measurements by balloon at 100,000 feet altitude above Guam, 4°N geomagnetic latitude.

523.165:523.74 1576

The Sun as a Source of Cosmic Rays of Intermediate Energies—J. Katzman. (*Canad. J. Phys.*, vol. 37, pp. 1207–1215; November, 1959.) Cosmic-ray intensity, as measured with a narrow-angle telescope and thick absorber, shows a sunspot-cycle variation. Correlations with F_2-layer ionization and solar RF flux are shown.

523.165:523.745 1577

Primary Cosmic-Ray Intensity near Solar Maximum—F. B. McDonald .(*Phys. Rev.*, vol. 116, pp. 462–463; October 15, 1959.) Results of measurements of proton and α-particle fluxes and energy spectra are given. Comparison is made with an electric-field model.

523.165:551.593.9 1578

Cherenkov Radiation in the Atmosphere—J. V. Jelley. (*Planet. Space Sci.*, vol. 1, pp. 105–111; April, 1959.) A review of theoretical and experimental work.

523.5 1579

Ambipolar Diffusion of a Meteor Trail and its Relation with Height—E. L. Murray. (*Planet. Space Sci.*, vol. 1, pp. 125–129; April, 1959.) Regression lines have been derived for the relation between log D and height, where D is the ambipolar diffusion coefficient. See 100 of 1956 (Weiss).

523.745:551.510.535 1580

A Daily Index of Solar Activity based on E-Layer Ionization (July 1937–December 1958)—C. M. Minnis and G. H. Bazzard. (*J. Atmos. Terr. Phys.*, vol. 17, pp. 57–64; December, 1959.) "The electron density in a Chapman layer can be related to the intensity of the incident solar ionizing radiation. This relation has been adopted as the basis for computing a daily index of the radiation intensity using the critical frequency of the E layer at Slough. Precautions have been taken to minimize errors due to irregularities in the behavior of the layer and to the difficulty in identifying the E-layer cusp. The standard deviation of the residual errors in the index is estimated to be 2 per cent. The index has been tabulated for the period 1 July 1957 to 31 December 1958."

550.385 1581

Rapid Fluctuations during Magnetic Disturbance—J. Lawrie. (*J. Atmos. Terr. Phys.*, vol. 17, pp. 145–149; December, 1959.) A numerically simple ratio is defined and used to examine space relationships of rapid geomagnetic fluctuations during disturbance.

550.385:539.16 1582

Geomagnetic Effects of High-Altitude Nuclear Explosions—A. G. McNish. (*J. Geophys. Res.*, vol. 64, pp. 2253–2265; December, 1959.) The observations discussed were made after the two Johnston Island explosions in August 1958, at four stations within 2000-km radius, and at Apia near the conjugate point [see also 3709 of 1959 (Matsushita)]. Effects at the first four observatories are attributed to overhead currents caused by increased ionization by γ rays, while effects at Apia are explained as being caused by artificial auroras.

550.385:539.16 1583

Simultaneous Recordings in France, at the Equator and in the Antarctic, of Magnetic Effects caused by the "Argus Experiment"—É. Selzer. (*Compt. rend. acad. sci., Paris*, vol. 249, pp. 1133–1135; September 28, 1959.) Geomagnetic disturbances were observed at French I.G.Y. stations for all three explosions.

550.385.37:061.3 1584

Symposium on Pulsations and Rapid Variations in Geomagnetism and Earth Currents—(*J. Geomag. Geoelect.*, vol. 10, pp. 135–225; 1959.) The text is given of the following papers read at a symposium in Tokyo, Jap., April 3–4, 1959.

a) **Ionizations in the Outer Atmosphere Inferred from Whistling Atmospherics**—J. Outsu and A. Iwai (pp. 135–142).

b) **Hydromagnetics in the Earth's Outer Atmosphere**—T. Tamao (pp. 143–150).

c) **The Acceleration of Particles in the Outer Atmosphere**—T. Obayashi (pp. 151–152).

d) **Morphology of S.S.C. and S.S.C.***—S. Abe (pp. 153–163).

e) **Some Remarks on the Morphology of Geomagnetic Bays**—N. Fukushima (pp. 164–171).

f) **Some Characters of Geomagnetic Pulsation *pt* and Accompanied Oscillation *spt***—K. Yanagihara (pp. 172–176).

g) **Morphology of the Geomagnetic Pulsation**—T. Watanabe (pp. 177–184.)

h) **Particles of Aurorae and Geomagnetic Pulsations**—Y. Kato and T. Watanabe (pp. 185–194).

i) **Hydromagnetic Oscillation of the Outer Ionosphere and Geomagnetic Pulsation**—T. Watanabe (pp. 195–202).

j) **Geomagnetic Pulsation accompanying the Intense Solar Flare**—Y. Kato, T. Tamao and T. Saito (pp. 203–207).

k) **On the Frequency of Geomagnetic Pulsation *pc***—T. Yoshimatsu (pp. 208–213).

l) **Studies of the Local Character of the Geomagnetic Pulsation *pc***—S. Utashiro (pp. 214–220).

m) **Preliminary Studies on the Daily Behaviour of Rapid Pulsation**—Y. Kato and T. Saito (pp. 221–225).

550.385.37:551.594.5 1585

Micropulsations in the Earth's Magnetic Field Simultaneous with Pulsating Aurora—W. H. Campbell. (*Nature, Lond.*, vol. 185, p. 677; March 5, 1960.) Preliminary results are given.

550.385.4 1586

Hydromagnetic Theory of Geomagnetic Storms—A. J. Dressler and E. N. Parker. (*J. Geophys. Res.*, vol. 64, pp. 2239–2252; December, 1959.) The sudden commencement of a magnetic storm is attributed to the collision of solar plasma with the geomagnetic field, the disturbance being propagated to earth by a hydromagnetic wave. The initial positive phase is attributed to sustained pressure by the plasma, the main negative phase by break-up and diffusion of the plasma, which is trapped in orbits in the Van Allen belt, and the recovery by conversion of trapped protons into neutral hydrogen.

551.507.362:061.3 1587

I.G.Y. Rockets and Satellites: A Report on the Moscow Meetings, August 1958—W. W. Kellogg. (*Planet. Space Sci.*, vol. 1. pp. 71–84; January, 1959.) A report of the Technical Symposia on Rockets and Satellites which formed part of the proceedings of the Fifth Meeting of C.S.A.G.I. in Moscow, July 31–August 9, 1958.

551.507.362.2+629.19 1588

Artificial Earth Satellites and Space Travel: Part 2—Satellite and Moon-Probe Design—C. W. M. Tilenius. (*VDI Z.*, vol. 102, pp. 85–92 and 121–127; January 21, and February 1, 1960.) A comparison is made of the design of satellites and moon probes launched up to about mid-1959 and details of their instrumentation are given. Part 1: 1215 of April.

551.507.362.2 1589

Application of Hansen's Theory to the Motion of an Artificial Satellite in the Gravitational Field of the Earth—P. Musen. (*J. Geophys. Res.*, vol. 64, pp. 2271–2279; December, 1959.) A numerical theory, suitable for solution by computer, which has been applied in the Vanguard program.

551.507.362.2 1590

Re-entry of the Sputnik I Rocket—I. Harris and R. Jastrow. (*Planet. Space Sci.*, vol. 1, pp. 37–39; January, 1959.) An analysis of radar observations of satellite 1957α. The probable point of impact was latitude 45° N, longitude 106°E, in Outer Mongolia.

551.507.362.2 1591

Decay of Spin in Sputnik I—J. W. Warwick. (*Planet. Space Sci.*, vol. 1, pp. 43–49; January, 1959.) A secular change in spin-fading rate which occurred during the period October 4–24, 1957 is used to determine the atmospheric density near perigee.

551.507.362.2 1592

Magnetic Damping of Rotation of Satellite 1958 β2—R. H. Wilson, Jr. (*Science*, vol. 130, pp. 791–793; September 25, 1959.) From radio observation of Vanguard I eddy-current induction theory gives a value of 0.115 ±0.001 G for the mean magnetic field normal to the spin axis of the satellite.

551.507.362.2 1593

Geomagnetic Rotational Retardation of Satellite 1959 α1 (Vanguard II)—R. H. Wilson, Jr. (*Science*, vol. 131, pp. 223–225; January 22, 1960.) Radio observations indicated a rapid exponential retardation of satellite rotation. Analysis of EM couples acting on the conducting and magnetic parts of the satellite gives a value of 0.158 G for the mean ambient geomagnetic field and confirms the eddy-current theory applied to Vanguard I (1952 above).

551.507.362.2:523.165 1594

Study of the Cosmic-Ray Soft Component by the 3rd Soviet Earth Satellite—S. N. Vernov, A. E. Chudakov, E. V. Gorchakov, J. L. Logachev, and P. V. Vakulov. (*Planet. Space Sci.*, vol. 1, pp. 86–93; April, 1959.)

551.507.362.2:551.510.535 1595

Measurement of Solar and Diurnal Effects in the High Atmosphere by Artificial Satellites—H. A. Martin and W. Priester. (*Nature, Lond.*, vol. 185, pp. 600–601; February 27, 1960.)

551.507.362.2:551.510.535 1596

Observations of the Russian Satellites and the Structure of the Outer Terrestrial Atmosphere—H. K. Paetzold. (*Planet. Space Sci.*, vol. 1, pp. 115–124; April, 1959.) Radio and optical observations are analyzed.

551.507.362.2:551.510.535 1597

The Determination of the Electron Distribution in the Upper Ionosphere from Satellite Doppler Observations—F. H. Hibberd and J. A. Thomas. (*J. Atmos. Terr. Phys.*, vol. 17, pp. 71–81; December, 1959.) By simultaneous reception at two frequencies, one of which is an approximate multiple of the other, a monotonic electron distribution can be determined exactly. The method is illustrated for Sputnik I.

551.507.362.2:551.510.535 1598

Derivation and Analysis of Atmospheric Density from Observations of Satellite 1958 Epsilon—G. F. Schilling and C. A. Whitney. (*Planet. Space Sci.*, vol. 1, pp. 136–145; April, 1959.)

551.507.362.2:551.510.535 1599

The Density Distribution in the Upper Atmosphere—K. H. Schmidt. (*Naturwiss.*, vol. 46, p. 138; February, 1959.) The results of measurements of atmospheric density made by earth satellites are plotted as a function of altitude in comparison with curves for two model atmospheres.

551.507.362.2:551.510.535 1600

Absorption and Electron Distribution in the F_2 Layer determined from Measurements of Transmitted Radio Signals from Earth Satellites—A. N. Kazantsev. (*Planet. Space Sci.*, vol. 1, pp. 130–135; April, 1959.) A comparison is made between measured and theoretically derived values of field strength of received signals on 20 mc when the satellite is in the region of maximum electron concentration and in regions above and below this level. Field-strength curves for distances up to 16,000 km are given.

551.507.362.2:621.317.361 1601

Measurement of the Doppler-Fizeau Effect with Artificial Satellites—G. Boudouris, J. Bournazel, and E. Vassy. (*Onde élect.*, vol. 39, pp. 934–938; December, 1959.) A simple method is described for measuring the Doppler frequency within ±1 cps by comparison with the signal from a calibrated LF oscillator.

551.507.362.2:621.391.812.33 1602

The Scintillation of Radio Signals from Satellites—K. C. Yeh and G. W. Swenson, Jr. (*J. Geophys. Res.*, vol. 64, pp. 2281–2286; December, 1959.) Signals from satellites 1957 α2, and 1958 δ2, recorded during a 20-month period, are analyzed for evidence of scintillation. Night-time scintillation correlates with ionospheric "spread F" and apparently originates at heights of about 220 km at latitudes greater than 40°N. Daytime scintillation appears to originate in smaller inhomogeneous regions below 220 km more widely distributed in latitude.

551.507.362.2:621.391.812.6 1603

Observations of Ionization Induced by Artificial Earth Satellites—J. D. Kraus, R. C. Higgy, D. J. Scheer, and W. R. Crone. (*Nature, Lond.*, vol. 185, pp. 520–521; February 20, 1960.) Major enhancements of WWV 20-mc signals occur 15 minutes before and 8 minutes after the time of nearest approach of 1958 δ. Radar echoes which appear to originate at range of 1958 δ are discussed.

551.510.53 1604

Energy Sources of the Upper Atmosphere—V. I. Krassovsky. (*Planet. Space. Sci.*, vol. 1, pp. 14–19; January, 1959.) Variable heating of the upper atmosphere is considered to be caused by electric currents which are induced by magnetic fields "frozen" into the corpuscular streams.

551.510.53:551.507.362 1605

An Interim Atmosphere derived from Rocket and Satellite Data—I. Harris and R. Jastrow. (*Planet. Space Sci.*, vol. 1, pp. 20–26; January, 1959.) A model atmosphere is proposed for temperatue latitudes at altitudes up to 400 km.

551.510.535 1606

Large-Scale Movements of Ionization in the Ionosphere—D. F. Martyn. (*J. Geophys. Res.*, vol. 64, pp. 2178–2179; December, 1959.) An instability mechanism for deviations in ionization density is suggested for which the predicted temporal and spatial morphologies appear to be consistent with those of the occurrence of sporadic E, spread F and radio-star scintillations.

551.510.535 1607

Fall-Day Auroral-Zone Atmospheric Structure Measurements from 100 to 188 km.—R. Horowitz, H. E. LaGow and J. F. Giuliani. (*J. Geophys. Res.*, vol. 64, pp. 2287–2295; December, 1959.) Atmospheric density and pressure profiles are obtained using measurements made with rocket-borne ionization gauges.

551.510.535 1608

A Relationship between the Lower Ionosphere and the [OI] 5577 Nightglow Emission—J. W. McCaulley and W. S. Hough. (*J. Geophys. Res.*, vol. 64, pp. 2307–2313; December, 1959.) Correlation is found between the 5577Å emission and radio echoes obtained with a 0.1–2 mc ionosonde.

551.510.535 1609

The Electron Density Distribution in the F Region of the Ionosphere—A. J. Hirsh. (*J. Atmos. Terr. Phys.*, vol. 117, pp. 86–95; December, 1959.) A theory of electron loss in the ionosphere [414 of 1957 (Bates & Massey)], is examined in numerical detail. Under certain conditions which are well defined, the theory leads to the type of $h'(f)$ curve observed in practice for the lower F region. See also 2579 of 1959 (Yonezawa *et al.*).

551.510.535 1610

Ionization below the Night-Time F Layer—J. E. Titheridge. (*J. Atmos. Terr. Phys.*, vol. 17, pp. 126–133; December, 1959.) Using the method described in 1616 below, the low-lying ionization for Slough and Watheroo has been studied throughout summer and winter nights during periods of maximum and minimum solar activity. The decay of ionization was consistent with an effective recombination coefficient of 2×10^{-8} cm³/sec.

551.510.535 1611

Travelling Disturbances Originating in the Outer Ionosphere—K. Bibl and K. Rawer. (*J. Geophys. Res.*, vol. 64, pp. 2232–2238; December, 1959.) The vertical velocity component of traveling disturbances coming from outside and propagating through the ionosphere is determined as 115 ±35 msec. Oscillation-like phenomena have a large range of quasi-periods between $\frac{1}{4}$ and 12 hours.

551.510.535:532.5:061.3 1612

International Symposium on Fluid Mechanics in the Ionosphere—(*J. Geophys. Res.*, vol. 62, pp. 2037–2238; December, 1959.) Review and verbatim report of the transactions of a symposium held in New York, July 9–15, 1959. Some of the papers presented are listed below, others have been abstracted separately.

a) **Constitution of the Atmosphere at Ionospheric Levels**—M. Nicolet (pp. 2092–2101).

b) **Ionizations and Drifts in the Ionosphere**—J. A. Ratcliffe (pp. 2102–2111).

c) **Measurements of Turbulence in the 80- to 100-km Region from the Radio Echo Observations of Meteors**—J. S. Greenhow and E. L. Neufeld (pp. 2129–2133).

d) **Scattering of Waves and Microstructure of Turbulence in the Atmosphere**—A. M. Oboukhov (pp. 2180–2187).

e) **Effect of a Magnetic Field on Turbulence in an Ionized Gas**—J. W. Dungey (pp. 2188–2191).

f) **Note on some Observational Characteristics of Meteor Radio Echoes**—P. M. Millman (pp. 2192–2194).

g) **On the Spectrum of Electron Density Produced by Turbulence in the Ionosphere in the Presence of a Magnetic Field**—I. D. Howells (pp. 2198–2199).

h) **Evidence of Elongated Irregularities in the Ionosphere**—B. Nichols (pp. 2200–2202).

i) **Geomorphology of Spread F and Characteristics of Equatorial Spread F**—R. W. H. Wright (pp. 2203–2207).

j) **An Interpretation of certain Ionospheric Motions in Terms of Atmsopheric Waves**—C. O. Hines (pp. 2210–2211).

k) **On the Influence of the Magnetic Field on the Character of Turbulence in the Ionosphere**—G. S. Golitsyn (pp. 2212–2214).

l) **Magnetohydrodynamics of the Small-Scale Structure of the F Region**—J. P. Dougherty (pp. 2215–2216).

m) **Electrodynamic Stability of a Vertically Drifting Ionospheric Layer**—J. A. Fejer (pp. 2217–2218).

n) **Turbulent Spectra in a Stably Stratified Atmosphere**—R. Bolgiano, Jr. (pp. 2226–2229).

o) **Relation of Turbulence Theory to Ionospheric Scatter Propagation Experiments**—A. D. Wheelon (pp. 2230–2231). Summary only.

551.510.535:550.385 1613

Geomagnetic Distortion of the F_2 Region on the Magnetic Equator: Part 2—H. Maeda. (*J. Geomag. Geoelect.*, vol. 11, pp. 1–5; 1959.) An extension of work described earlier [see 3257 of 1955 or 424 of 1956 (Hirono and Maeda)] to study the relation between diurnal variations of f_0F_2 for years of different sunspot number and the phase of geomagnetic S_q variations. F_2-region distortion is explained by vertical ionization drift due to the es field extended from the E region.

551.510.535:551.594.6 1614

Constant Ionosphere Height for Audio-Frequency Propagation—F. Hepburn. (*Nature, Lond.*, vol. 185, p. 599; February 27, 1960.) From an analysis of smooth-type waveforms (3312 of 1959) a constant height of 83 km ±2 km has been estimated for winter storms. There was no systematic variation with the onset of night-time conditions.

551.510.535:621.391.812.63 1615

The Calculation of Real and Virtual Heights of Reflection in the Ionosphere—J. E. Titheridge. (*J. Atmos. Terr. Phys.*, vol. 17, pp. 96–109; December, 1959.) A method is described by which an $N(h)$ profile can be calculated using only about 20 readings of either the ordinary or extraordinary $h'(f)$ trace. The calculation, which takes about 15 minutes, can be used in reverse to derive an $h'(f)$ curve from an $N(h)$ profile.

551.510.535:621.391.812.63 616

The Use of the Extraordinary Ray in the Analysis of Ionospheric Records—J. E. Titheridge. (*J. Atmos. Terr. Phys.*, vol. 17, pp. 110–125; December, 1959.) It is shown that, by using the ordinary and extraordinary traces, estimates may be made of the electron content and also the electron density distribution in a) the region represented by reflections at frequencies less than $f_{\min}$; b) in the valley between the E and F layers.

551.510.535(98):523.164 1617

An Example of Heavy Absorption in the V.H.F. Band in the Arctic Ionosphere—L. Harang and J. Tröim. (*Planet. Space Sci.*, vol. 1, pp. 102–104; April, 1959.) Observations of meteor echoes and of RF noise from the Cassiopeia source, in the 40–45-mc band show very heavy absorption in the early morning of July 7, 1958.

551.594 1618

Observations of Unusual Radiofrequency Noise Emission and Absorption at 80 Mc/s—H. J. A. Chivers and H. W. Wells. (*J. Atmos. Terr. Phys.*, vol. 17, pp. 13–19; December, 1959.) The noise enhancements observed during periods of solar activity are classified as smooth or abrupt. While smooth changes occur in both day and night hours, the abrupt increases are observed only near local midnight. The smooth enhancements occur almost simultaneously with the absorption of radiation in a sector of the northern sky.

551.594.5 1619

Hydrogen Emission and Two Types of Auroral Spectra—G. I. Galperin. (*Planet. Space Sci.*, vol. 1, pp. 57–62; January, 1959.) Various characteristics of auroral activity including radio reflections have been correlated with the hydrogen emission.

551.594.5:523.164 1620

Auroral Ionization and the Absorption and Scintillation of Radio Stars—H. J. A. Chivers and J. S. Greenhow. (*J. Atmos. Terr. Phys.*, vol. 17, pp. 1–12; December, 1959.) The absorption of radiation from Cygnus, when observed at low latitudes, and radar back-scatter echoes are related to a layer associated with auroral activity.

551.594.5:539.16 1621

Artificial Auroras Resulting from the 1958 Johnston Island Nuclear Explosions—J. M. Malville. (*J. Geophys. Res.*, vol. 64, pp. 2267–2270; December, 1959.)

551.594.5:621.391.8 1622

A Daytime Maximum of Oblique Auroral Reflexions Observed in the Auroral Zone—A. Egeland, B. Hultqvist, and J. Ortner. (*Nature, Lond.*, vol. 185, p. 519; February 20, 1960.) Observations made at 92.8 mc over the period March–June 1959 show a daytime maximum between 1200–1600 MET.

551.594.5:621.391.812.6.029.63 1623

Observed Characteristics of an Ultra-High-Frequency Signal Traversing an Auroral Disturbance—James, Bird, Ingalls, Stone, Day, Lockwood, and Presnell. (*See* 1749.)

551.594.6 1624

A Comparison of Sferics as Observed in the Very-Low-Frequency and Extremely-Low-Frequency Bands—L. R. Tepley. (*J. Geophys. Res.*, vol. 64, pp. 2315–2329; December, 1959). The VLF component is almost always followed by a component of extremely low frequency (10–1000 cps), but about one-third of these ELF components are not preceded by VLF components. Positive-polarity ELF waveforms predominant during daytime and their median amplitudes always exceed those of the negative-polarity waveforms which predominate at night.

551.594.6 1625

Sweepers—N. C. Gerson and W. H. Gossard. (*J. Atmos. Terr. Phys.*, vol. 17, pp. 82–85; December, 1959.) Sweepers are atmospherics which are present in the HF band predominating between 20 and 30 mc. Many of them occur in trains where the period between successive sweepers is nearly constant. Frequency coverage for any sweeper can vary from 75 to 1500 kc and may have a duration varying between 0.1 and 18 seconds.

551.594.6:621.391.812.63 1626

The Propagation of Electromagnetic Waves in Ionized Gases (with Special Reference to "Whistlers"): Parts 1 & 2.—Northover. (*See* 1759.)

LOCATION AND AIDS TO NAVIGATION

621.396.96 1627

In Fog and Rain—Sight, IR or Radar?—M. E. Seymour. (*Electronics*, vol. 33, pp. 64–66; January 29, 1960). Tables and curves are given for the comparison of infrared and radar systems of detection under various weather conditions.

621.396.96 1628

Experimental Determination of the Radar Scatter Cross-Section of Cylindrical Metal Objects—E. Meyer, H. Kuttruff, and H. Severin. (*Z. angew. Phys.*, vol. 11, pp. 1–6; January, 1959.) Measurements of the scatter cross-section of metal cylinders with length/diameter ratio 10:1 were made using EM and acoustic waves. The cross section was measured as a function of angle of incidence and of ratio $l:\lambda$ in the range 1.8–25, and was found to increase monotonically with this ratio.

621.396.96:621.317.3 1629

Noise Temperature in a Radar System—H. H. Grimm. (PROC. IRE, vol. 48, p. 246; February, 1960.) Note of measurements made on an L-band radar system using parametric amplifying circuits.

621.396.963.325 1630

Statistical Properties, Frequency Spectrum and Suppression of Low Frequencies in Radar P.P.I. Displays—H. Groll and E. Vollrath. (*Nachrichtentech. Z.*, vol. 12, pp. 33–40; January, 1959.) The statistical distribution of targets as a function of display radius is determined and the relation of radar-signal frequency spectrum to display content is discussed. The effect of low-frequency suppression by means of signal-controlled carrier modulation is described.

MATERIALS AND SUBSIDIARY TECHNIQUES

531.788:621.385.032.94 1631

Outgassing caused by Electron Bombardment of Glass—B. J. Todd, J. L. Lineweaver, and J. T. Kerr. (*J. Appl. Phys.* vol. 31, pp. 51–55; January, 1960.) The method of measuring outgassing by bombardment with 20-kev electrons is described. Oxygen was found to be the main constituent of the gas produced by the electron bombardment.

531.788.7 1632

The Magnetron Gauge: a Cold-Cathode Vacuum Gauge—P. A. Redhead. (*Canad. J. Phys.*, vol. 37, pp. 1260–1271; November, 1959.) An ionization gauge with axial magnetic field is described. The ion-current/pressure relation is linear over the range $10^{-4}-5+10^{-10}$ mm Hg and the sensitivity about 45 times greater than that of a standard Bayard-Alpert gauge.

535.5:061.3 1633

International Symposium on Residual Gases in Electron Tubes and Similar High-Vacuum Systems—(*Nuovo Cim.*, vol. 12, supplement pp. 297–329; 1959). Summaries, some in English, are given of papers presented at a symposium held at Como, September 23–25, 1959.

535.215:539.23 1634

Formation of Caesium Antimonide: Part 1—Electrical Resistivity of the Film of Caesium-Antimony System—K. Miyake. (*J. Appl. Phys.*, vol. 31, pp. 76–81; January, 1960.) The preparation of Cs-Sb films in which the atomic ratio of Cs to Sb varied from 0.91 to 4.86 is described. Measurements of their resistivity in the range −70° to +70°C are given, and thermal activation energies deduced.

535.215:546.48'221 1635

Contactless Electrical Excitation of Electrons in CdS Single Crystals—K. W. Böer and U. Kümmel. (*Z. Naturf.*, vol. 13a, pp. 698–699; August, 1958.) Conductivity glow curves were obtained using an experimental arrangement in which direct contact between metal electrodes and crystal surface is avoided by means of mica inserts. Results agree with those obtained by direct-contact methods.

535.215:546.48'221 1636

Application of Electro-optical Effects in the Analysis of the Electrical Conduction Process in CdS Single Crystals—K. W. Böer, H. J. Hänsch, and U. Kümmel. (*Z. Phys.*, vol. 155, pp. 170–183; May 22, 1959.) Description of electro-optical methods for rendering visible current and electric-field inhomogeneities (see also 3757 of 1959). Photographs of some of the effects obtained are reproduced and discussed.

535.215:546.482'21 1637

Inhomogeneous Field Distribution in CdS Single Crystals in the Range of High Field Strengths—K. W. Böer. (*Z. Phys.*, vol. 155, pp. 184–194; May 22, 1959.) Optical effects obtained by the method discussed in 1636 above are ascribed to internal field-strength inhomogeneities. A mechanism is proposed which may lead to a revised conception of the process of electrical breakdown.

535.215:546.48'221:548.0 1638

Dislocations in Two Types of CdS Crystals.—D. C. Reynolds and S. J. Czyzak. (*J. Appl. Phys.*, vol. 31. pp. 94–98; January, 1960.)

535.215:546.883 1639

Field Dependence of Photoelectric Emission from Tantalum—J. L. Gumnick and D. W. Juenker. (*J. Appl. Phys.*, vol. 31, pp. 102–108; January, 1960.) An accelerating electric field was used.

535.37:546.47'221 1640

Some Properties of Zinc Sulphide Crystals Grown from the Melt—A. Addamiano and M. Aven. (*J. Appl. Phys.*, vol. 31, pp. 36–39; January, 1960.) Density and stability of structure were studied for annealing temperatures in the range 700°–1150°C.

535.37:546.48'221 1641

Exciton Spectrum of Cadmium Sulphide—D. G. Thomas and J. J. Hopfield. (*Phys. Rev.*, vol. 116, pp. 573–582; November 1, 1959.) Measurements of reflectance and fluorescent spectra at 77° and 4.2°K are described. The reflectivity results lead to the idenitification of three exciton series which are discussed with reference to the band structures at $\mathbf{k}=0$.

535.37:546.48'221 1642

A.C. Impedance Measurements on Insulated CdS Crystals—H. Kallmann, B. Kramer, and G. M. Spruch. (*Phys. Rev.*, vol. 116, pp. 628–632; November 1, 1959.)

537.227 1643

Variation in Ferroelectric Characteristics of Lead Zirconate Titanate Ceramics due to Minor Chemical Modifications—R. Gerson. *J. Appl. Phys.*, vol. 31, pp. 188–194; January, 1960.) The changes in the properties of lead zirconate titanate due to niobium or lanthanum additions are attributed to a high domain-wall mobility in response to applied electric fields.

537.227 1644

Structure of Ferroelectric Domains in Triglycine Sulphate—H. Toyoda, S. Waku, and H. Hirabayashi. (*J. Phys. Soc. Japan*, vol. 14, pp. 1003–1011; August, 1959.) Domain structures are studied by etching in various alcohols.

537.227 1645

Etch Pits corresponding to Dislocations in Ferroelectric Guanidinium Aluminum Sulphate Hexahydrate—T. Nakamura. (*J. Phys. Soc. Japan*, vol. 14, pp. 1022–1029; August, 1959.)

537.227:621.318.57 1646

Model for Switching and Polarization Reversal in Colemanite—H. H. Wieder. (*J. Appl. Phys.*, vol. 31, pp. 180–187; January, 1960.) A model based on random nucleation followed by extensive sideways displacement of the 180 degrees nucleated domains is proposed for the switching mechanism. It gives good agreement with experimental characteristics.

537.228.1 1647

Piezoelectric Properties of Polycrystalline Lead Titanate Zirconate Compositions—D. A. Berlincourt, C. Cmolik, and H. Jaffe. (Proc. IRE, vol. 48, pp. 220–229; February, 1960.) Data are given for the low-signal elastoelectric properties of compositions ranging from $PbZr_{0.48}Ti_{0.52}O_3$ to $PbZr_{0.6}Ti_{0.4}O_3$.

536.228.1 1648

Reduction of Frequency-Temperature Shift of Piezoelectric Crystals by Application of Temperature-Dependent Pressure—E. A. Gerber. (Proc. IRE. vol. 48, pp. 244–245; February, 1960.) A control system is described for use where crystal ovens are not practicable. Pressure is applied to the crystal by a bimetal strip.

537.228.1:549.514.51 1649

Effect of Initial Stress in Vibrating Quartz Plates—A. D. Ballato and R. Bechmann. (Proc. IRE, vol. 48, pp. 261–262; February, 1960.) Experimental curves show the effect on the frequency of vibration of compressional stress applied to the edge.

537.311.32:546.22:539.12.04 1650

Bombardment Conductivity and Photoconductivity in Rhombic Sulphur—P. J. Dean, B. S. H. Royce, and F. C. Champion. (*Proc. Phys. Soc.*, vol. 75, pp. 119–135; January 1, 1960.)

537.311.33+537.226 1651

The Influence of Field Emission on the Distribution of Strong Fields in Solids—E. I. Adirowitsch (Adirovich). (*Z. Phys.*, vol. 155, pp. 195–205; May 22, 1959.) The kinetics of changes in inhomogeneous field distribution in solid dielectrics and semiconductors are investigated with reference to Böer's interpretation of the phenomena (1637 above).

537.311.33 1652

Shapes of Etch Hillocks and Pits and their Correlation with Measured Etch Rates—B. A. Irving. (*J. Appl. Phys.*, vol. 31, pp. 109–111; January, 1960.) Gives a condition for hillock stability additional to those of Batterman (1186 of 1958).

537.311.33 1653

Theory of Inversion Layers on Semiconductor Surfaces—E. Groschwitz and R. Ebhardt. (*Z. angew. Phys.*, vol. 11, pp. 9–19; January, 1959.) The physical properties and construction of inversion layers are investigated, without and with the application of an external field.

537.311.33 1654

On the Frequency Dependence of the Field Effect in Semiconductors: Part 2—A. E. Yunovich. (*Fiz. Tverdogo Tela*, vol. 1, pp. 1092–1101; July, 1959.) Results of an analysis for the case when current carriers of both signs are present in the bulk of the semiconductor and on its surface, show that the frequency dependence of the field effect is governed by certain time constants. Expressions are obtained for the effective mobility and conditions are given under which minority carriers can be neglected. For earlier work see 2788 of 1958 and *Zh. tekh. Fiz.*, vol. 28, pp. 698–693; April, 1958.

537.311.33 1655

The Effect of an Electric Field on the Decay of Excess Carriers in Semiconductors—B. K. Ridley. (*Proc. Phys. Soc.*, vol. 75, pp. 157–161; January 1, 1960.) "Sweep-out" effects increase the decay rate and can affect the form of the decay. Expressions are given for the decay rate when the decay curve is approximately exponential; results agree with experimental data for one sample.

537.311.33 1656

Minority-Carrier Current in a Linearly Graded Drift Field—D. P. Kennedy. (*J. Appl. Phys.*, vol. 31, pp. 218–219; January, 1960.) Equations are given, with the results of some numerical calculations.

537.311.33 1657

On a Relation between Various Theories for the Scattering of Current Carriers in Semiconductors—G. E. Pikus. (*Zh. tekh. Fiz.*, vol. 28, pp. 2390–2401, November, 1958.) Mathematical analysis based on the Bardeen-Shockley deformation-potential theory. When the energy minimum is not located in the center of the Brillouin zone the Berthe-Sommerfeld scattering theory leads to the same results as the deformation-potential method.

537.311.33 1658

Application of the Equivalent Orbital Method to the Study of Band Structure in $A^{III}B^{V}$ Compounds—A. I. Gubanov and A. A. Nran'yan. (*Fiz. Tverdogo Tela*, vol. 1, pp. 1044–1052; July 1959.)

537.311.33:535.215:538.63 1659

New Parallel Photoelectromagnetic Effect—A. Amith. (*Phys. Rev.*, vol. 116, pp. 330–333; October 15, 1959.) The effect described is the net flow of carrier pairs in a direction transverse to the applied magnetic field, due to a difference in surface recombination velocities of opposite parallel surfaces. Theory is given and experiments on an *n*-type Ge crystal 0.2×1.2×0.7 cm are described.

537.311.33:535.215–15 1660

The Theory of Optical Properties of Electronic Semiconductors in the Infrared Region of the Spectrum—V. I. Cherepanov. (*Fiz. Tverdogo Tela*, vol. 1, pp. 1035–1043; July, 1959.)

537.311.33:536.21.083 1661

Measurement of Thermal Conductivity of Semiconductors near Room Temperature—A. V. Ioffe and A. F. Ioffe. (*Zh. tekh. Fiz.*, vol. 28, pp. 2357–2363; November, 1958.) Brief description of an improved apparatus and discussion of its performance.

537.311.33:537.32 1662

Method of Eliminating Heat from Semiconductor Cooling Devices—E. A. Kolenko, A. G. Shcherbina and V. G. Yur'ev. (*Zh. tekh. Fiz.*, vol. 28, pp. 2543–2545; November, 1958.) Brief description of the method, and list of useful substances which have a high latent heat of fusion.

537.311.33:537.324 1663

Investigation of the Intermetallic Compound Bi_2Te_3 and the Solid Solutions $Bi_{2-x}Sb_xTe_3$ and $Bi_2Te_{3-x}Se_x$ with regard to their Suitability as Material for Semiconductor Thermoelements—U. Birkholz. (*Z. Naturforsch.*, vol. 13a, pp. 780–792; September, 1958.) Thermoelectric characteristics were determined for a number of materials. A thermoelement of *p*-type $Bi_{0.6}Sb_{1.4}Te_3$ with *n*-type Bi_2Te_3 had an experimentally determined efficiency of 2.14×10^{-3} per °C, equivalent to a maximum of Peltier-effect cooling of 80°C.

537.311.33:546.24 1664

On the Structure of the Hole Band in Tellurium—L. I. Korovin and Yu. A. Firsov. (*Zh. tekh. Fiz.*, vol. 28, pp. 2417–2427; November, 1958.) The observed close dependence of the absorption coefficient on the polarization of incident infrared radiation is used to define more accurately the hole band structure in Te. It is shown that this band has one degenerate extreme for $\boldsymbol{k}=0$ or two degenerate extrema along the k_z axis.

537.311.33:546.24 1665

Hot Holes in Tellurium—Y. Kania. (*J. Phys. Soc. Japan*, vol. 14, p. 1118; August, 1959). Measurements made at 77°K indicate that the energy loss of holes in Te is due mainly to acoustic-phonon scattering.

537.311.33:[546.28+546.289 1666

Germanium and Silicon Liquidus Curves—C. D. Thurmond and M. Kowalchik. (*Bell Sys. Tech. J.*, vol. 39, pp. 169–204; January, 1960.) Supplementing existing results with new measurements, it is reported that all but 2 of 26 binary-system liquidus curves can be described by a two-constant equation. Evidence is cited indicating that the constants of the equation can be used to estimate the excess free energy of the solutions. 55 references.

537.311.33:[546.28+546.289 1667

Ion-Bombardment Etching of Silicon and Germanium—J. A. Dillon, Jr., and R. M. Oman. (*J. Appl. Phys.*, vol. 31, pp. 26–28; January, 1960.) Etch patterns greatly differing from those produced by chemical etching are obtained.

537.311.33:[546.28+546.289 1668

Mass-Spectrometer Determination of the Amount and Composition of Gases Absorbed on the Surface of Germanium and Silicon Single Crystals—V. M. Kozlovshaya. (*Fiz. Tverdogo Tela*, vol. 1, pp. 1027–1034; July, 1959.)

537.311.33:[546.28+546.289 1669

Solid Solubilities of Impurity Elements in Germanium and Silicon—F. A. Trumbore. (*Bell Sys. Tech. J.*, vol. 39, pp. 205–233; January, 1960.) New results for Pb-Ge, Zn-Ge, In-Ge, Sb-Si, Ga-Si, and Al-Si systems are compared with existing data. The correlation of solid solubilities k° and $k^{\circ\prime}$ with heats of solution and atom size of impurity elements is considered. 90 references.

537.311.33:546.28 1670

Thermal Expansion of Silicon—L. Maissel. (*J. Appl. Phys.*, vol. 31, p. 211; January, 1960.) New measurements of the expansion coefficient in the temperature range 50–850°C, for (111) and (110) crystal orientations.

537.311.33:546.28 1671

The Temperature Dependence of the Low-Level Lifetime and Conductivity Mobility of Carriers in Silicon—D. M. Evans. (*J. Electronics Control*. vol. 7, pp. 112–122; August, 1959.) "The temperature dependence of the low-level lifetime in silicon has been found to be consistent with that expected from the theory based on a low level of injection, a low density of recombination centres and a single energy level for the recombination centres. The temperature dependence of the conductivity mobility has also been determined."

537.311.33:546.28 1672

Impurity Effects upon Mobility in Silicon—R. A. Logan and A. J. Peters. (*J. Appl. Phys.*, vol. 31, pp. 122–124; January, 1960.) Measurements on sufficiently pure silicon show a mobility/temperature variation of the form $T^{-1.5}$ for *n*-type and T^{-2} for *p*-type material, at temperatures below 100°K. At higher temperatures the mobility is further reduced, presumably by optical-mode scattering.

537.311.33:546.28 1673

High-Field Effect in Boron-Doped Silicon—R. D. Larrabee. (*Phys. Rev.*, vol. 116, pp. 300–301; October 15, 1959.) A linear current/voltage relation was observed at 77°K up to fields of 10^4 v/cm.

537.311.33:546.28:538.569.4 1674

Millimetre Cyclotron Resonance in Silicon—C. J. Rauch, J. J. Stickler, H. J. Zeiger, and G. S. Heller. (*Phys. Rev. Lett.*, vol. 4, pp. 64–66; January 15, 1960.) Measurements are reported at 2.1 mm λ on high-purity *n*-type Si between 1.2° and 50°K.

537.311.33:546.28:539.12.04 1675

Measurement of the Lifetime of Carriers Generated in Silicon by Electron Bombardment—A. Vapaille. (*Compt. rend. acad. sci., Paris*, pp. 648–650; vol. 249.) Measurements of lifetime down to 1 μsec have been made by a pulse deflection method. The resistance of a *p*-type crystal increased under the effect of bombardment at energies below 15 kev; above 20 kev the resistance decreased. An unusual variation of life-time with temperature was observed in a high-resistivity *p*-type crystal.

537.311.33:546.28:539.12.04 1676

Energy Levels in Neutron-Irradiated *n*-type Silicon—G. Kupprecht and C. A. Klein. (*Phys. Rev.*, vol. 116, pp. 342–343; October 15, 1959.)

537.311.33:546.289 1677

Procedure against Thermal Conversion in Germanium—O. Mikami. (*Rep. Elect. Commun. Lab., Japan*, vol. 7, pp. 204–206; June, 1959.) The Ge wafer is etched in a CP-4 solution, washed in distilled deionized water and annealed for four hours at 490–500°C in a quartz tube which has been washed with aqua regia and fluoric acid.

537.311.33:546.289 1678

On the Influence of Ga and Fe on the Thermal Conductivity of Germanium—G. B. Abdullaev, G. M. Aliev, and N. I. Chetverikov. (*Zh. tekh. Fiz.*, vol. 28, pp. 2368–2371; November, 1958.)

537.311.33:546.289 1679

Interaction between Arsenic and Aluminum in Germanium—J. O. McCaldin. (*J. Appl. Phys.*, vol. 31, pp. 89–94; January, 1960.) It is found that As diffusing in Ge at 800°C is attracted to regions of heavy Al doping, and these regions show an enhanced solubility for As.

537.311.33:546.289 1680

Electronic Surface States and the Cleaned Germanium Surface—P. Handler and W. M. Portnoy. (*Phys. Rev.*, vol. 116, pp. 516–526; November, 1959.) The surface conductivity and the field-induced surface conductivity are shown to be almost independent of temperature over the range 77°–300°K. A qualitative two-dimensional band model is presented which correlates most of the experimental results.

537.311.33:546.289 1681

Remarks on the Oxidation, after Heat Treatment, of Germanium Surfaces Oriented along a (111) Plane—L. Gouskor. (*Compt. rend. acad. sci., Paris*, vol. 249, pp. 671–673; August 3, 1959.)

537.311.33:546.289 1682

The Nature of Relaxation Processes in the Field Effect—V. I. Lyashenko and N. S. Chernaya. (*Fiz. Tverdogo Tela*, vol. 1, pp. 1005–1014; July, 1959.) Report of an investigation of long-term changes in the field effect in *n*- and *p*-type Ge in different atmospheres.

537.311.33:546.289:537.32:538.63 1683

The Magnetic Variation of Thermoelectric Power of Germanium at Low Temperatures—J. Erdmann. (*Z. Naturforsch.*, vol. 13a, pp. 650–662; August, 1958.) Measurements were made on Ge single crystals with various donor or acceptor concentrations in a transverse magnetic field in the temperature range 20°–90°K. Results are in qualitative agreement with Appel's theory (555 of February). See also 2794 of 1958 (Erdmann *et al.*).

537.311.33:546.289:539.23 1684

Remarks on some Electrical Properties of Very Thin Films of Germanium—C. Uny. (*Compt. rend. acad. sci., Paris*, vol. 249, pp. 645–647; August 3, 1959.) Aging effects and deviations from Ohm's law are described. Ge films show closer analogies with films of Cu than with those of Ag or Au (3350 of 1959).

537.311.33:546.431'42–31 1685

The Influence of Oxygen, Hydrogen and Water Vapour on the Electrical Conductivity of Barium Oxide and Barium-Strontium Oxide—J. Rudolph. (*Z. Naturforsch.*, vol. 13a, pp. 757–767; September, 1958.)

537.311.33:546.47–31 1686

On the Problem of Exo-electron Emission of Semi-conductors—R. Merold. (*Naturwiss.*, vol. 46, pp. 138–139; February, 1959.) An interpretation of exo-electron emission effects in ZnO is given leading to some conclusions as to the mechanism of this process.

537.311.33:[546.681’241+546.682’241 1687
The Infrared Absorption of Gallium Telluride (Ga_2Te_3) and Indium Telluride (In_2Te_3)—G. Harbeke and G. Lautz. (*Z. Naturforsch.*, vol. 13a, pp. 775–779; September, 1958.) Evaluation and interpretation of results obtained in measurements described in 3121 of 1958, and comparison with similar investigations of other authors.

537.311.33:546.681’241 1688
The Structure Sensitivity of Gallium Telluride (Ga_2Te_3) to Very Small Additions of Cu—G. Harbeke and G. Lautz. (*Z. Naturforsch.*, vol. 13a, pp. 771–775; September, 1958.) See 3031 of 1959.

537.311.33:546.681’86 1689
Some Data on Diffusion and the Effect of Impurities on the Electrical Properties of Gallium Antimonide—B. I. Boltaks and Yu. A. Gutorov. (*Fiz. Tverdogo Tela*, vol. 1, pp. 1015–1021; July, 1959.)

537.311.33:546.682’19 1690
The Form of the Conductivity Band of Indium Arsenide—D. Geist. (*Z. Naturforsch.*, vol. 13a, pp. 699–700; August, 1958.) Results of susceptibility measurements are compared with those derived from theoretical calculations of band structure.

537.311.33:546.682’19 1691
Infrared Absorption of *n*-Type Indium Arsenide—F. Matossi. (*Z. Naturforsch.*, vol. 13a, pp. 767–770; September, 1958.) Measurements were made on InAs with donor concentration about $10^{16}cm^{-3}$ at temperatures in the range 120°–475°K. For investigations of absorption in *p*-type InAs see 3892 of 1958 (Matossi and Stern).

537.311.33:546.682’86 1692
The Formation Enthalpy of III/V Compounds—A. Schneider and K. Klotz. (*Naturwiss.*, vol. 46, p. 141; February, 1959.) The enthalpy of InSb was determined by a direct calorimetric method.

537.311.33:546.682’86 1693
Growth of InSb Crystals in the (111) Polar Direction—H. C. Gatos, P. L. Moody, and M. C. Lavine. (*J. Appl. Phys.*, vol. 31, pp. 212–213; January, 1960.) Discussion of an atomic model put forward to explain the differences observed in growth of InSb crystals depending on the polarity of the seed crystal.

537.311.33:546.682’86 1694
Behaviour of InSb Surfaces during Heat Treatment—D. Haneman. (*J. Appl. Phys.*, vol. 31, pp. 217–218; January, 1960.) Deals with the formation and movement of hillocks on the InSb surface.

537.311.33:546.682’86 1695
Thermomagnetic Effects in InSb.—V. P. Zhuze and I. M. Tsidil’kovskiĭ. (*Zh. tekh. Fiz.*, vol. 28, pp. 2372–2381; November, 1958.) An investigation of the transverse and longitudinal Nernst-Ettingshausen effects, the thermo-EMF, the conductivity and Hall effect of seven InSb samples with differing impurity content. It is shown that for temperatures between 120° and 765°K the scattering of current carriers occurs chiefly in the acoustic mode.

537.311.33:546.682.86:538.569.4 1696
Spin Resonance of Conduction Electrons in InSb—G. Bemski. (*Phys. Rev. Lett.*, vol. 4, pp. 62–64; January 15, 1960.) A summary of spin-resonance phenomena in the concentration range 2×10^{14}–3×10^{15} electrons/cm^3.

537.311.33:[546.821–31+546.281–31 1697
Electrical Conductivity of Certain Titanium and Vanadium Oxides—S. M. Ariya and N. I. Bogdanova. (*Fiz. Tverdogo Tala*, vol. 1, pp. 1022–1026. July, 1959.)

537.311.33:621.317.3 1698
Further Consideration of Bulk Lifetime Measurement with a Microwave Electrodeless Technique—Jacobs, Ramsa, and Brand. (*See* 1729.)

537.533.8 1699
Variation of Secondary Electron Emission of Single Crystals with Angle of Incidence—A. J. Dekker. (*Phys. Rev. Lett.*, vol. 4, pp. 55–57; January 15, 1960.)

537.533.8 1700
On the Correlation of the Coefficients of Secondary Electron Emission from Nonmetals Caused [respectively] by Ion and Electron Bombardment—V. M. Lovtsov. (*Zh. tekh. Fiz.*, vol. 28, pp. 2469–2472; November, 1958.) Brief investigation of the physico-chemical properties of Mg-MgO and KCl film-type emitters. Results are shown graphically

537.533.8 1701
Electron Reflection Reflection and Secondary Electron Emission from Metallic Surfaces for Low-Energy Primary Electrons: Part 2—I. M. Bronshteĭn and V. V. Roshchin. (*Zh. tekh. Fiz.*, vol. 28, pp. 2476–2486; November, 1958.) Investigation on the secondary emission from Pt, Cu, Ag, Au and Al. Part 1: 234 of January.

537.533.8:539.23 1702
Temperature Dependence of the Secondary Electron Emission Coefficient of NaCl Films—M. V. Gomoyunova. (*Zh. tekh. Fiz.*, vol. 28, pp. 2473–2475; November, 1958.) It is shown that in the temperature range −196° to 320°C the emission coefficient can be expressed by Dekker’s formula (3194 of 1954).

537.583 1703
Variation of the Work Function of an Electron from a Metal under the Influence of an Absorbed Layer of Molecules of Barium Oxide—N. D. Morgulis. (*Fis. Tverdogo Tela*, vol. 1, pp. 1125–1132; July, 1959). Experimental investigation of the temperature dependence of the work function and the effect of BaO molecules deposited on the base layer of a metal.

538.221 1704
Spontaneous Magnetizations of some Gadolinium Alloys—S. Arajs and D. S. Miller. (*J. Appl. Phys.*, vol. 31, pp. 213–215; January, 1960.) Special attention is paid to the variation of magnetization with temperature.

538.221 1705
Internal Ferromagnetic Resonance in Small Cobalt Particles—J. C. Anderson. (*Proc. Phys. Soc.*, vol. 75, pp. 33–39; January 1, 1960.)

538.221 1706
Internal Ferromagnetic Resonance in Magnetite—J. C. Anderson and B. Donovan. (*Proc. Phys. Soc.*, vol. 75, pp. 149–151; January 1, 1960.) Results are quoted for a colloidal suspension of magnetite over the temperature range 30°–90°C.

538.221 1707
Investigation of Weak Ferromagnetism in the $MnCO_3$ Single Crystal—A. S. Borovik-Romanov. (*Zh. Eksp. Teor. Fiz.*, vol. 36, pp. 766–781; March, 1959.) Description of experiments carried out in the temperature range 1.3–300°K. A ferromagnetic moment is observed only in the base plane; along the trigonal axis the crystal is paramagnetic. In the temperature range 1.5–23°K, the ferromagnetic moment is proportional to the square of the temperature. Theoretical formalas are obtained which are qualitatively in agreement with experimental results.

538.221:537.122 1708
On the Interaction between Conduction Electrons in Ferromagnetics—A. I. Akhiezer and I. Ya. Pomeranchuk. (*Zh. Eksp. teor. Fiz.*, vol. 36, pp. 859–862; March, 1959.) Analysis showing that in a ferromagnetic material there is an additional attraction between conduction electrons which is due to spin-wave exchange.

538.221:621.318.124 1709
Cobalt-Free Ferrites with Perminvar Loop—E. Röss. (*Naturwiss.*, vol. 46, p. 65; January, 1959.) Note on polycrystalline Mn-Zn ferrites with relatively stable perminvar effect.

538.221:621.318.124:548.73 1710
X-Ray Study of Ferromagnetic Domains in Cobalt Zinc Ferrite—K. M. Merz. (*J. Appl. Phys.*, vol. 31, pp. 147–154; January, 1960.) Diffraction curves of the (400) reflection broadened when a magnetic field was applied to the crystal.

538.221:621.318.134 1711
Determination of Molecular Field Coefficients in Ferrimagnets—G. T. Rado and V. J. Folen. (*J. Appl. Phys.*, vol. 31, pp. 62–68; January, 1960.) An improved analytical method is presented for determining the three molecular field coefficients which yield the best agreement between the Néel theory and the experimental curve of saturation moment /temperature for a given ferrimagnetic material. The analysis of experimental data on samples of Li and Mg-Fe ferrites is given.

538.221:621.318.134 1712
Rectangular Hysteresis Loop Ferrites with Large Barkhausen Steps—A. P. Greifer and W. J. Croft. (*J. Appl. Phys.*, vol. 31, pp. 85–88; January, 1960.) Observations have been made at low temperatures of large discontinuities (steps) in the 60-cps hysteresis loops of polycrystalline ferrites containing copper. At the temperature for step formation, which is a function of copper content, the coercivity decreases and the loop squareness approaches unity.

538.221:621.318.134 1713
Temperature Dependence of Magnetic Crystal Anisotropy of Nickel Ferrite—G. Elbinger. (*Naturwiss.* vol. 46, p. 140; February, 1959.) The anisotropy constant was determined in the temperature range −185° to +450°C from measurements of magnetic torque.

538.221:621.318.134 1714
The Thermomagnetic Behaviour of Pure Nickel Ferrite—L. F. Bates and H. Clow. (*Proc. Phys. Soc.*, vol. 75, pp. 17–23; January 1, 1960.) The small heat exchanges produced during the magnetization process were measured for a rod specimen at −10°C and +18°C. Some support is found for the Lilley disperse-field theory.

538.221:621.318.134 1715
Magnetization and Coercive Force of Nickel-Zinc Ferrites particularly with Added Impurities—W. Holzmüller and T. Kampf. (*Nachrichtentech. Z.*, vol. 9, pp. 44–46; January, 1959.) Measurements were made on ferrites containing impurities up to 15 per cent in volume, of BeO, ThO_2,Cr_2O_3 and WO_2, and results show that irreversible magnetization effects are due to Bloch-wall displacements.

538.221:631.318.134 1716

Concerning the Arbitrary Reversal of the Magnetic Polarity of Mn-Mg and Ni-Zn Ferrites—V. V. Kobelev and I. I. Nadashkevich. (*Fiz. Tverdogo Tela*, vol. 1, pp. 1140–1146; July, 1959.) The investigation shows that the periodic application of current pulses of alternating polarity to toroidal ferrite cores produces an individual hysteresis cycle which is shifted in the direction of the initial magnetic state.

538.221:621.318.134 1717

The Variation of Magnetization of a Single Crystal of $PbO \cdot 6Fe_2O_3$ as a Function of the Field—R. Pauthenet and G. Rimet. (*Compt. rend. acad. sci., Paris*, vol. 249, pp. 656–658; August 3, 1959.) Results of experiments on uniaxial crystals are explained in terms of domain phases. See also 3806 of 1959 (Giron and Pauthenet).

538.221:621.318.134 1718

Magnetic Properties of the Mixed Garnets $(3-x)Y_2O_3 \cdot xGd_2O_3:5Fe_2O$,—E. E. Anderson, J. R. Cunningham, Jr., and G. E. McDuffie. (*Phys. Rev.*, vol. 116, pp. 624–625; November 1, 1959.)

538.221:621.318.134 1719

Neutron Study of the Crystal and Magnetic Structures of $MnFe_{2-t}Cr_tO_4$—S. J. Pickart and R. Nathans. (*Phys. Rev.*, vol. 116, pp. 317–322; October 15, 1959.) Powder neutron-diffraction measurements at temperatures down to 4.2°K are used for an accurate determination of the nuclear-structure parameters.

538.221:621.318.134 1720

Magnetic Properties of the Manganese Chromite-Aluminates—P. L. Edwards. (*Phys. Rev.*, vol. 116, pp. 294–300; October 15, 1959.) The mixed-crystal spinel series $MnCr_{2-t}Al_tO_4$ has been studied experimentally; results are compared with theory.

538.221:621.318.134:538.569.4 1721

Some Peculiarities of Multiplet Ferromagnetic Resonance in Ferrites—V. N. Lazukin. (*Zh. Eksp. Teor. Fiz.*, vol. 36, pp. 682–689; March, 1959.) Investigation at 9200 and 14,640 mc of multiple resonances in inhomogeneously magnetized single and polycrystalline samples at room temperature and at liquid-nitrogen temperature. Results are shown for various spherical and ring-shaped samples of Mn-Zn and Mn-Mg ferrites.

538.221:621.318.134:538.569.4 1722

Theory of Ferromagnetic Resonance in Rare-Earth Garnets: Part 2—Line Widths—P. G. de Gennes, C. Kittel, and A. M. Portis. (*Phys. Rev.*, vol. 116, pp. 323–330; October 15, 1959.) Theoretical results describe the order of magnitude and the temperature dependence of observed line widths assuming that the relaxation time of the relevant rare-earth ions is $\approx 10^{-12}$ second at 400°K. Part 1: 1322 of April (Kittel).

538.221:621.395.625.3 1723

Particle Interaction in Magnetic Recording Tapes—J. G. Woodward and E. DellaTorre. (*J. Appl. Phys.*, vol. 31, pp. 56–62; January, 1960.) In two different recording tapes particle interaction was found to be appreciable and a significant factor in determining the bulk magnetic properties and the recording performance of tapes.

538.222 1724

Simultaneous Determination of Particle Size and Magnetization in the Ångstrom Region by the Measurement of the Collective Paramagnetism—A. Knappwost. (*Naturwiss.*, vol. 46, pp. 65–66; January, 1959.) The investigation of spontaneously magnetized domains of size from 10 to about 100 A is facilitated by the method described.

538.222:539.2 1725

Threshold Energy for Lattice Displacement in α-Al_2O_3—G. W. Arnold and W. D. Compton. (*Phys. Rev. Lett.*, vol. 4, pp. 66–68; January 15, 1960.)

538.652 1726

The Saturation Magnetostriction of Polycrystals—R. R. Birss. (*Proc. Phys. Soc.*, vol. 75, pp. 8–16; January 1, 1960.) Relations between the single-crystal and polycrystalline saturation magnetostriction constants are derived for cubic materials.

MATHEMATICS

512.99:538.3 1727

The Method of Combinative Numbers (Nombres Combinatifs) in the Study of Electromagnetic Fields—Zlatev. (*See* 1558.)

MEASUREMENTS AND TEST GEAR

621.3.018.41(083.74) 1728

Frequency Measurement of Standard-Frequency Transmissions against Caesium-Beam Resonator Standard—S. N. Kalra. (*Canad. J. Phys.*, vol. 37, pp. 1328–1329; November, 1959.) A table shows the frequency deviations of the 60-kc MSF, 16-kc GBR and 60-kc KK2XE1 transmissions as measured daily in Ottawa during August 1959, and the mid-monthly mean frequency of WWV. Figures are to be published monthly, *ibid.*

621.317.3:537.311.33 1729

Further Consideration of Bulk Lifetime Measurement with a Microwave Electrodeless Technique—H. Jacobs, A. P. Ramsa, and F. A. Brand. (PROC. IRE, vol. 48, pp. 229–233; February, 1960.) Describes a method of measurement of the lifetime of excess carriers in semiconductors using a steady light source, which does not involve electrode attachments and also reduces the effects of surface recombination.

621.317.31:537.312.62 1730

Measuring Critical Current in Cryogenic Circuits—J. I. Pankove and R. Drake. (*Electronics*, vol. 33, pp. 52–53; January 22, 1960.) Details are given of test equipment which automatically traces the characteristic curve of a cryogenic device, supplying a current of up to 2A to the contact for periods <100 μsec.

621.317.335:621.315.212 1731

Continuous Measurement of Capacitance of Coaxial Cables during Manufacture—D. Wolff. (*Nachrichtentech. Z.*, vol. 12, pp. 29–32; January, 1959.)

621.317.6:621.391.883.2 1732

A Simple Technique for Measuring the Signal-to-Noise Ratio at the Output of a Pulsed Sinusoid Matched Filter—H. E. White. (PROC. IRE, vol. 48, pp. 241–242; February, 1960.)

621.317.7:621.319.4 1733

An Oscillating Capacitor of High Stability—von Ardenne and Klar. (*See* 1516.)

621.317.723:621.375.4 1734

A Multirange Electrometer Amplifier Using Variable Feedback—J. H. Leck and W. E. Austin. (*Electronic Engrg.*, vol. 32, pp. 106–107; February, 1960.) A description of a stable electrometer amplifier using transistors and a miniature electrometer tube, which has proved satisfactory for measuring currents down to 10^{-15}A.

621.317.726 1735

A Peak Voltmeter intended for the Measurement of Isolated High-Voltage Pulses—G. Giralt and E. Krouk. (*Compt. rend. acad. sci., Paris*, vol. 249, pp. 1042–1044; September 21, 1959.) Details are given of the blocking method described earlier [920 of 1959 (Giralt)]. The duration of the pulse may be from 0.1 μs to 10 ms. The use of a special air capacitor enables measurements to be made of voltages up to 400 kv.

621.317.733 1736

Measurement of Impedance in the Audio-Frequency Range—D. Karo. [*Engineer* (*London*), vol. 208, pp. 687–690; November 27, 1959.] A bridge circuit is described in which the number of resistance standards is reduced to the minimum and the effect of the remaining residuals eliminated by two consecutive balancing procedures. Results obtained with the new circuit are compared with those given by conventional bridges.

621.317.75:621.374 1737

Transistorized Slicer Analyses Signal Amplitude—T. A. Bickart. (*Electronics*, vol. 33, pp. 70, 72; January 29, 1960.) A circuit for the measurement of amplitude probability density functions is described, comprising inverter, diode AND gate, Schmitt trigger and integrator. See 1976 of 1959.

621.317.79.029.6:551.510.62 1738

Limit of Spatial Resolution of Refractometer Cavities—W. J. Hartman. (*J. Res. Nat. Bur. Stand.*, vol. 64D, pp. 65–72; January /February, 1960.) Filter factors are derived which determine an upper limit for the wave numbers for which refractometer measurements can be used to calculate the spectrum of refractivity.

OTHER APPLICATIONS OF RADIO AND ELECTRONICS

537.376:681.61 1739

Electroluminescent Alphanumeric Display—T. Hamburger. (*Electronics*, vol. 33, pp. 49–51; January 22, 1960.) Information from a conventional typewriter keyboard is displayed sequentially on five alphanumeric indicators. The five characters can be selectively or totally erased. The indicators are in effect lossy capacitors and require a 230-volt 400-cps excitation to give the rated brightness.

621.36+621.56]:537.322 1740

Figure of Merit for Thermionic Energy Conversion—N. S. Rasor. (*J. Appl. Phys.*, vol. 31, pp. 163–167; January, 1960.) The optimum performance for emission-limited thermionic energy conversion is derived. Methods of reducing fundamental performance limitations are briefly discussed and a figure of merit is given which applies to both thermionic and thermoelectric conversion.

621.36+621.56]:537.322 1741

Calculation of Efficiency of Thermoelectric Devices—B. Sherman, R. R. Heikes, and R. W. Ure, Jr. (*J. Appl. Phys.*, vol. 31, pp. 1–16; January, 1960.) A procedure has been developed for the exact calculation of the efficiency of thermoelectric generators and cooling devices in which the parameters of the materials have arbitrary temperature dependence. Approximate and exact methods are employed and compared in the numerical evaluation of the results.

621.384.612.11 1742

Zero-Gradient Synchrotron at the Argonne National Laboratory—[*Engineer* (*London*), vol. 208, pp. 492–495; October 23, 1959.] Description of the 12.5-Bev proton synchrotron under construction at Lemont, Illinois.

621.384.7 1743

The Splitting of a Beam of Particles into Two Beams by means of an Electrostatic Bi-

prism—A. Septier. (*Compt. rend. acad. sci., Paris*, vol. 249, pp. 662–664; August 3, 1959.) Calculations show that the two emergent beams are not deformed.

621.385.833 1744
Factors affecting Contrast and Resolution in the Scanning Electron Microscope—T. E. Everhart, O. C. Wells, and C. W. Oatley. (*J. Electronics Control*, vol. 7, pp. 97–111; August, 1959.)

621.387.462:621.382.2 1745
Tiny Semiconductor is Fast, Linear Detector—S. S. Friedland, J. W. Mayer, and J. S. Wiggins. (*Nucleonics*, vol. 18, pp. 54–56, 59; February, 1960.) A shallow diffused Si p-n junction operated with reverse bias forms a space-charge region which acts as an ionization chamber capable of giving a high-resolution response proportional to incident particle energy.

621.398:551.507.362.2 1746
Data Conversion Circuits for Earth-Satellite Telemetry—D. N. Carson and S. K. Dhawan. (*Electronics*, vol. 33, pp. 82–84; January 15, 1960.) Details are given of two pulse-height analyzer circuits suitable for use in artificial satellites.

621.398:629.19 1747
Solid-State Guidance for Able-Series Rockets—R. E. King and H. Low. (*Electronics*, vol. 33, pp. 60–63; January 29, 1960.) Circuits used in the second-stage rocket for pitch, yaw and roll control are described.

PROPAGATION OF WAVES

621.391.81+621.396]:(98):061.3 1748
Conference on Arctic Communication—Kirby and Little. (*See* 1776.)

621.391.812.6.029.63:551.594.5 1749
Observed Characteristics of an Ultra-High-Frequency Signal Traversing an Auroral Disturbance—J. C. James, L. E. Bird, R. P. Ingalls, M. L. Stone, J. W. B. Day, G. E. K. Lockwood, and R. I. Presnell. [*Nature* (*London*), vol. 185, pp. 510–512; February 20, 1960.] Signals transmitted on a frequency of 440 mc from a station in the auroral zone were observed at two mid-latitude stations after reflection from the moon. Results show a rapid fluctuation of the polarization of the signal received and an increase in the rate of fading, but no measurable absorption.

621.391.812.62 1750
An Extract Earth-Flattening Procedure in Propagation around a Sphere—L. Y. C. Koo and M. Katzin. (*J. Res. Nat. Bur. Stand.*, vol. 64D, pp. 61–64; January/February, 1960.) Exact differential equations for the spherical geometry are obtained in terms of equations of the plane-earth type, and solutions of these hold for arbitrarily large heights and distances.

621.391.812.62.029.55 1751
Measurements of Coastal Deviation of High-Frequency Radio Waves—C. W. McLeish. (*J. Res. Nat. Bur. Stand.*, vol. 64D, pp. 57–59; January/February, 1960.) "The angular deviation of the phase front of a wave propagated across a fresh water shoreline has been measured over the frequency range from 3 to 20 Mcs. The deviation is found to be roughly half that which theoretically would be obtained if the same sites were adjacent to infinitely conducting surfaces."

621.391.812.62.029.63 1752
A Note regarding the Mechanism of U.H.F. Propagation Beyond the Horizon—A. D. Watt, E. F. Florman, and R. W. Plush. (PROC. IRE, vol. 48, p. 252; February, 1960.) Results are given which provide some evidence for the existence of a "scatter volume."

621.391.812.62.029.63 1753
Investigations of Propagation over Radio-Link Paths Within and Beyond Optical Range at 1.1 to 1.3 Gc/s—U. Kühn. (*Tech. Mitt. BRF, Berlin*, vol. 3, pp. 32–41; October, 1959.) Statistical analysis of results of long-term measurements made on five different paths in East Germany. For path lengths beyond optical range night-time field-strength increases $>$40db over daytime values were frequently observed. For earlier results see 3095 of 1959.

621.391.812.62.029.64+621.396.677.73 1754
Over-Sea Propagation of Microwaves and Anti-reflected-Wave Antenna—S. Kawazu, S. Kato, and K. Morita. (*Rep. Elect. Commun. Lab., Japan*, vol. 7, pp. 171–191; June, 1959.) An experimental three-element stacked array for suppressing the reflected wave is described. Measured field strengths are compared with those obtained using a single horn and with calculated values.

621.391.812.624 1755
Tropospheric Scatter Propagation and Atmospheric Circulations—W. F. Moler, and D. B. Holden. (*J. Res. Nat. Bur. Stand.*, vol. 64D, pp. 81–93; January/February, 1960.) Scattering angle and intensity of dielectric fluctuations at high wave numbers are found to be dependent on the refractive layering and thermal stability of the air mass which are known to be functions of the vertical velocity in the atmosphere. It is shown that the direction and magnitude of the vertical velocity can be inferred from the upper tropospheric wind velocity divergence, and received scattered signals are well correlated with this quantity.

621.391.812.624 1756
Frontal Perturbation of a Tropospheric Scatter Path—D. R. Hay and G. E. Poaps. (*Canad. J. Phys.*, vol. 37, pp. 1272–1282; November, 1959.) The fading rate of 500-mc transmissions over an 85-mile path is found to rise when the path is disturbed by a weather front situated so that any part of the frontal zone lies between the surface and 3000 feet at the path mid-point.

621.391.812.63 1757
On the Mode of Propagation in the E Layer—W. R. Piggott and J. Bhattacharyya. (*J. Atmos. Terr. Phys.*, vol. 17, pp. 150–157; December, 1959.) Examination of f_0E data shows that the mode of propagation near the maximum of the E layer is quasi-transverse for all values of dip from 0 degrees to approximately 89 degrees. It is confirmed that the traces extending about $f_H/2$ above f_0E are due to sporadic-E and not to magneto-ionic effects.

621.391.812.63 1758
Radio Scattering in the Lower Ionosphere—H. G. Booker. (*J. Geophys. Res.*, vol. 64, pp. 2164–2177; December, 1959.) Radio scattering phenomena observed in the frequency range 30–100 mc indicate the presence of irregularities of electron density with corrugation wavelengths from 120 to 360 meters. The irregularities are approximately isotropic.

621.391.812.63:551.594.6 1759
The Propagation of Electromagnetic Waves in Ionized Gases (with Special Reference to "Whistlers"): Parts 1 and 2—F. H. Northover. (*J. Atmos. Terr. Phys.*, vol. 17, pp. 158–178; December, 1959.) An investigation of the propagation of waves along more or less complete columns of ionization which follow approximately the lines of force of the earth's magnetic field. In Part 1 a general theory of wave propagation in conducting gases is developed. In Part 2 the propagation of the plane-wave mode along stationary columns is examined.

621.391.812.63:621.391.826.2 1760
Around-the-World Echoes Observed on a Transpolar Transmission Path—J. Ortner. (*J. Geophys. Res.*, vol. 64, pp. 2464–2467; December, 1959.) Investigation of the College, Alaska—Kiruna path during winter 1958/1959, using an 18-mc back-scatter sounder and a Yagi pointing northward, showed a long delay signal attributable to an around-the-world path. The signal strength sometimes equalled that of the short-path pulses, indicating tilted reflection paths above the D region.

621.391.812.63.029.45 1761
Transmission Loss Curves for Propagation at Very Low Radio Frequencies—J. R. Wait. (IRE TRANS. ON COMMUNICATIONS SYSTEMS, vol. CS-6, pp. 58–61; December, 1958. Abstract, PROC. IRE, vol. 47, p. 494; March, 1959.)

621.391.812.63.029.45:621.396.67:621.315.1 1762
A Very-Low-Frequency Antenna for Investigating the Ionosphere with Horizontally Polarized Radio Waves—Macmillan, Rusch, and Golden. (*See* 1496.)

621.391.812.8:551.510.535 1763
The Calculation of the M.U.F. Factor for a Nonparabolic Ionospheric Layer—M. D. Vickers. (*J. Atmos. Terr. Phys.*, vol. 17, pp. 34–45; December, 1959.) "A method is described for calculating the ray path of a radio wave through the ionosphere as represented by an $N(h)$ profile based on experimental data. A few such paths are calculated and from these m.u.f. factors are obtained. These factors are compared with those which would have been obtained had the existing methods of calculation been used. In most cases the differences are less than 4 per cent."

621.391.814.2 1764
Layered-Earth Propagation in the Vicinity of Point Barrow, Alaska—G. M. Stanley. (*J. Res. Nat. Bur. Stand.*, vol. 64D, pp. 95–97; January/February, 1960.) "The relative field strength of a vertically polarized low-frequency radio signal was measured as a function of distance over several radial paths in the vicinity of Point Barrow, Alaska. The attenuation of the recorded signal was very much less than predicted by the theory of propagation of a ground wave signal over a plane, homogeneous, infinitely conducting earth. The analysis of these data in terms of a plane, layered, finitely conducting earth appears to resolve the anomaly."

RECEPTION

621.376.23 1765
Detecting Signals by Polarity Coincidence—B. M. Rosenheck. (*Electronics*, vol. 33, pp. 67–69; January 29, 1960.) Details are given of a type of dual-input phasemeter for the detection of weak signals in the frequency range 1–500 cps in a high noise background.

621.391.821 1766
Determination of the Amplitude Probability Distribution of Atmospheric Radio Noise from Statistical Moments—W. G. Crichlow, C. J. Roubique, A. D. Spaulding, and W. M. Beery. (*J. Res. Nat. Bur. Stand.*, vol. 64D, pp. 49–56; January/February, 1960.) An empirically derived graphical method is presented and possible errors are discussed.

621.391.821 1767
Measured Frequency Spectra of Very-Low-Frequency Atmospherics—T. Obayashi. (*J. Res. Nat. Bur. Stand.*, vol. 64D, pp. 41–48; January/February, 1960.) New continuously recording spectroscopes have been developed for the frequency ranges 1–10 kc and 5–70 kc. Observations with the equipment provide further experimental proof of the mode theory of VLF propagation.

621.391.821:539.16 1768
Effects of High-Altitude Nuclear Explosions on Radio Noise—C. A. Samson. (*J. Res. Nat. Bur. Stand.*, vol. 64D, pp. 37–40; January /February, 1960.) Atmospheric noise recorded at Kekaha, Hawaii, on frequencies between 13 kc and 20 mc fell by up to 32 db during the hour following the first explosion.

621.396.62:621.397.62 1769
The Combined Television/Radio Receiver and its Problems—R. S. Hildersley. (*J. Brit. IRE*, vol. 20, pp. 155–166; February, 1960.) Circuit details of a combined receiver are described. The sound IF circuits incorporate a double superheterodyne system and the frequency of the RF oscillator is stabilized in band II using a point-contact Ge diode as a variable-reactance device.

621.396.621 1770
Transformerless Circuits for Broadcast Receivers—R. C. V. Macario and N. E. Broadberry. (*Wireless World*, vol. 66, pp. 110–113; March, 1960.) Various circuits are simplified by taking advantage of the greater versatility of resistors, capacitors and transistors, to permit the omission of transformers and other wire-wound components.

621.396.662:621.372.632 1771
One-Tube Oscillator Mixers for TV and F.M. Tuners—E. H. Hugenholtz. (*Electronics*, vol. 33, pp. 76–79; January 15, 1960.) The circuits described use either a single triode tube as oscillator mixer or a semi-conductor diode as mixer with a triode or pentode oscillator tube. Spurious coupling is limited by balanced bridge networks and the isolating action of the diode. Results are better than those obtained with conventional circuits.

621.396.665:621–526 1772
The Application of Linear Servo Theory to the Design of A.G.C. Loops—W. K. Victor and M. H. Brockman. (PROC. IRE, vol. 48, pp. 234–238; February, 1960.) Expressions are derived specifying the performance of an agc system with respect to step and ramp changes in signal level, frequency response, receiver gain error as a function of receiver noise, etc. Close agreement with measured values is achieved.

621.396.666 1773
Evaluation of I.F. and Base-Band Diversity Combining Receivers—R. T. Adams and B. M. Mindes. (IRE TRANS. ON COMMUNICATIONS SYSTEMS, vol. CS-6, pp. 8–13; June, 1958. Abstract, PROC. IRE, vol. 46, pp. 1665–1666; September, 1958.)

STATIONS AND COMMUNICATION SYSTEMS

621.376.53 1774
A S/N Improvement Factor on P.A.M.-F.M. whose Received Pulse is Cosine-Squared—A. Watanabe. (PROC. IRE, vol. 48, pp. 257–258; February, 1960.) Formulas are derived for the signal/noise improvement factor when low-pass filters and integrated demodulation circuits are used. Figures are given for typical cases.

621.396:681.84.087.7 1775
New Stereophonic Broadcasting System—G. D. Browne. (*Brit. Commun. Electronics*, vol. 7, pp. 204–205; March, 1960.) General features of a fully compatible time-multiplex system are described.

621.396+621.391.81](98):061.3 1776
Conference on Arctic Communication—R. C. Kirby and C. G. Little (*J. Res. Nat. Bur. Stand.*, vol. 64D, pp. 73–80; January/February, 1960.) Brief report of the conference held at Boulder, Colo., March 3–6, 1959, with abstracts of the twenty-two papers presented.

621.396.2:621.391.812.624 1777
Dependence of the Maximum Range of Tropospheric Scatter Communications on Antenna and Receiver Noise Temperatures—A. H. Hausman. (IRE TRANS. ON COMMUNICATIONS SYSTEMS, vol. CS-6, pp. 35–38; December, 1958. Abstract, PROC. IRE, vol. 47, p. 494; March, 1959.)

621.396.65:621.395.665.1 1778
Compandor Loading and Noise Improvement in Frequency Division Multiplex Radio-Relay Systems—E. M. Rizzoni. (PROC. IRE, vol. 48, pp. 208–220; February, 1960.) "Graphical and numerical means are developed to compute the additional effective loading caused by the use of syllable compandors on the input of a multichannel radio-relay system, and to evaluate the noise improvement yielded by the compandor in a telephone channel."

621.396.932 1779
Mobile Maritime Service. Routes: Spain-South America, Spain-Persian Gulf—R. Gea Sacasa. (*Rev. Telecommunicación, Madrid*, vol. 14, pp. 7–20; September, 1959.) Signal-strength assessments of ships' transmissions received at Cadiz are related to forecasts by the Gea method. See also 3859 of 1959.

SUBSIDIARY APPARATUS

621.3.087.4:621.395.625.3 1780
More Bandwidth for Magnetic Recorders—D. R. Steele. (*Electronics*, vol. 33, pp. 44–47; January 8, 1960.) Details are given of the design of recorder circuits having a bandwidth 250 cps–250 kc to take advantage of recent increase in recording-head response.

621.314.63:621.382.2 1781
Some Performance Parameters of Silicon Junction Power Rectifiers—D. R. Coleman. (*Electronic Engrg*, vol. 32, pp. 98–102; February, 1960.) The temperature dependence of the characteristics of Si rectifiers, and temperature control in terms of thermal resistance are discussed. A method is given for the calculation of power dissipation and ratings.

621.316.721/.722:621.382.3 1782
Compensation of the Effect of Temperature on the Reference Voltage of Transistor Stabilized Power Supplies—É. Cassignol, P. Chauson, G. Giralt, and J. C. Polisset. (*Compt. rend. acad. sci., Paris*, vol. 249, pp. 59–661; August 3, 1959.) The voltage/temperature characteristic of the reference source (Zener diode or primary cell) is compensated by that of the base-emitter region of the transistor error amplifier. See 3642 of 1958 (Cassignol and Giralt).

621.316.722:621.318.435.3 1783
A Transductor Regulator for Stabilized Power Supplies—A. N. Heightman. (*J. Brit. IRE*, vol. 20, pp. 105–123; February, 1960.) A description is given of a single-core full-wave transductor circuit and its mode of operation. A tube-type regulator to deal with rapid disturbances is also described. Both regulators are incorporated in a stabilized 250-volt, 1-ampere power supply.

621.316.722.078.3 1784
Economy in the Series Stabilizer—D. J. Collins, and J. R. Pearce. (*Electronic Engrg.*, vol. 32, pp. 95–97; February, 1960.) Consideration of the efficiency of series stabilizer circuits under almost constant load conditions. A resistive shunt to the series element can improve efficiency.

TELEVISION AND PHOTOTELEGRAPHY

621.397:621.317(083.74) 1785
I.R.E. Standards on Television: Measurement of Differential Gain and Differential Phase, 1960—(PROC. IRE, vol. 48, pp. 201–208; February, 1960.) Standard 60 I.R.E. 23. S1.

621.397:621.391 1786
Video Information Theory—P. Neidhardt. (*NachrTech.*, vol. 9, pp. 18–23; January, 1959.) The application of the concepts and results of communication theory to the transmission of television signals is considered with the intention of formulating a specific video information theory.

621.397:621.391.837 1787
Investigations on the Replacement of the Subjective Assessment of Picture Quality by a Physical Criterion—W. Kroebel and G. Moll. (*Z. angew. Phys.*, vol. 11, pp. 27–35; January, 1959.) See also 4222 of 1959 (Kroebel).

621.397:621.391.837 1788
The Visibility of Picture Details of Moving Objects in Television—I. Bornemann. (*Nachrichtentech. Z.*, vol. 9, pp. 8–12; January, 1959.) The causes of the losses in detail entropy in the reproduction of moving objects are analyzed.

621.397.13:535–1/3 1789
A High-Grade Industrial Television Channel with reference to Infrared Operation—J. H. Taylor. (*J. Brit. IRE*, vol. 20, pp. 77–85; January, 1960.) Details are given of the system design including vidicon camera head, amplifier, control unit and monitor with reference to normal requirements. Infrared operation is discussed.

621.397.132 1790
A Review of Colour Television in the U. K.—R. D. A. Maurice. (*Electronic Engrg.*, vol. 32, pp. 68–73; February, 1960.)

621.397.132 1791
Monochrome Reproduction of Colour TV Signal—R. D. A. Maurice. (*Electronic Tech.*, vol. 37, pp. 116–119; March, 1960.) In a color-television system using the standard NTSC method of gamma correction the deterioration in orthochromatism of the monochrome compatible picture can be reduced by the presence of the dot pattern due to the chrominance subcarrier. A "notch" or subcarrier-elimination filter is thus undesirable in monochrome receivers.

621.397.132 1792
The Change in Skin-Colour Tints caused by Phase Errors in Colour Television—P. Neidhardt. (*Nachrichtentech. Z.*, pp. 4–7; January, 1959.) From a consideration of the color changes which can be tolerated and their relation to phase errors originating in the receiver it is concluded that phase errors of ±10 degrees are not objectionable.

621.397.332.12 1793
Reduction of Television Bandwidth by Frequency-Interlace—E. A. Howson and D. A. Bell. (*J. Brit. IRE*, vol. 20, pp. 127–136; February, 1960.) A method analogous to the NTSC color television system is used to obtain a bandwidth reduction of a monochrome signal by a factor of 2:1. Various interference effects are discussed.

621.397.335 1794
Timebase Synchronization and Associated Problems—P. L. Mothersole. (*J. Brit. IRE*, vol. 20, pp. 57–72; January, 1960.) The requirements of timebase oscillator and synchronization circuits are discussed with reference to both positive and negative modulation systems. Examples of these and noise-limiting circuits together with the effects of noise on synchronization are given.

621.397.612:621.318.57 1795
A Television Master Switcher—B. Mars-

den. (*J. Brit. IRE*, vol. 20, pp. 47–53; January, 1960. Discussion.) Switching methods are reviewed. The use of crystal diodes enables a low-consumption, reliable and compact switching system to be built with a response substantially flat to 6 mc. Reference is made to development work in which transistor pulse generators are used to achieve vision switching between successive frames of the television waveform.

621.397.62:621.396.62 1796

The Combined Television/Radio Receiver and its Problems—Hildersley. (*See* 1769.)

621.397.743 1797

The Technical Limits to Full Television Coverage of Germany by Wireless Transmission—W. Scholz. (*Elektrotech. Z.*, vol. 80, pp. 548–550; August 11, 1959.) 30 per cent of the area of the German Federal Republic cannot be covered by wireless transmission in the dm range because of multipath propagation due to the nature of the terrain. Distribution of received programs by cable offers a solution to the problem.

621.397.743 1798

Television Relay Links in the Č.S.R.—A. Ditl. (*Nachrichtentech. Z.*, vol. 9, pp. 23–25; January, 1959.) Description of radio-link equipment in use in Czechoslovakia.

621.397.743.029.64 1799

Microwave Television Mobile Relay for Outside Broadcasting—J. Polonsky. (*J. Brit. IRE*, vol. 20, pp. 91–102; February, 1960.) Principal causes of distortion and problems of cross-talk in microwave systems are discussed and a brief description is given of equipment operating in the range 6400–6900 mcs.

TUBES AND THERMIONICS

621.382.22 1800

Dipole Mode of Minority Carrier Diffusion with Reference to Point-Contact Rectification—B. R. Gossick. (*J. Appl. Phys.*, vol. 31, pp. 29–35; January, 1960.) An analysis of diffusion from a point source is used to investigate the importance of the dominant higher (dipole) mode relative to the fundamental (unipole) mode. The dipole mode is found to offer superior HF performance, which is partially offset by an inferior dc characteristic.

621.382.22 1801

The Germanium Microwave Crystal Rectifier—A. C. MacPherson. (IRE Trans. on Electron. Devices, vol. ED-6, pp. 83–90; January, 1959. Abstract, Proc. IRE, vol. 47, p. 612; April, 1959.)

621.382.23 1802

Conductance and Voltage Transfer Coefficient of a Semiconductor Diode in the Transient State—E. I. Adirovich. (*Fiz. Tverdogo Tela*, vol. 1, pp. 1115–1124; July, 1959.) Frequency, phase and transient characteristics of a circuit with a *p-n* junction and a series ohmic resistance are calculated. Characteristic time constants and critical frequencies are derived and a method of determining diode parameters, in particular for measurement of low values of lifetime, is described.

621.382.23 1803

Gallium Arsenide Tunnel Diodes—K. G. Hambleton, J. J. Low, and R. J. Sherwell. [*Nature* (*London*), vol. 185, pp. 676–677; March 5, 1960.] Characteristics of experimental Zn-doped GaAs diodes are noted.

621.382.23 1804

Pressure Dependence of the Current/Voltage Characteristics of Esaki Diodes—S. L. Miller, M. I. Nathan, and A. C. Smith. (*Phys. Rev. Lett.*, vol. 4, pp. 60–62; January 15, 1960.) Measurements on narrow-junction diodes at room temperature and at pressures up to 30,000 kg/cm^2 are reported and results are compared with theory. See 1784 of 1958 (Esaki).

621.382.23:546.289:535.34-15 1805

Investigation of Induced Absorption of Infrared Radiation in a Germanium Diode—Yu. I. Ukhanov. (*Zh. tekh. Fiz.*, vol. 28, pp. 2410–2416; November, 1958.) Quantitative investigation of the variation of infrared absorption in a Ge junction diode due to injected holes. The cross-section and effective mass of absorption centers are calculated.

621.382.23:621.316.722 1806

The Characteristics and Applications of Zener (Voltage-Reference) Diodes—J. A. Chandler. (*Electronic Engrg.*, vol. 32, pp. 78–86; February, 1960.)

621.382.23:621.318.57 1807

Electrical Properties of Gold-Doped Diffused Silicon Computer Diodes—A. E. Bakanowski and J. H. Forster. (*Bell Sys. Tech. J.*, vol. 39, pp. 87–104; January, 1960.) Theoretical investigations show that, to a first approximation, reverse recovery time is inversely proportional to gold atom concentration. This is supported by experimental evidence for gold concentrations in the range 8×10^{16} cm^{-3} to 1.2×10^{15} cm^{-3} (recovery times 0.7–35 mμsec). Accompanying changes in reverse and forward currents are also considered.

621.382.23:621.372.44 1808

***P-N-P* Variables-Capacitance Diodes**—J. F. Gibbons and G. L. Pearson (Proc. IRE, vol. 48, pp. 253–255; February, 1960.) A simplified circuit model is used to derive the properties of the device and the design and fabrication are described.

621.382.3:621.317.7 1809

Automatic Measurement of Transistor Beta—E. P. Hojak. (*Electronics*, vol. 32, pp. 114–115; December 4, 1959.) The base current is automatically varied until a predetermined collector current is obtained. The final base current is a direct measure of beta.

621.382.3.01 1810

On the Use of Physical rather than Four-Pole Parameters in a Standard Transistor Specification—D. F. Page. (Proc. IRE, vol. 48, p. 261; February, 1960.) Comment on 1008 of 1959 (Armstrong).

621.382.333 1811

On Calculating the Current Gain of Junction Transistors with Arbitarry Doping Distributions—H. L. Armstrong. (IRE Trans. on Electron Devices, vol. ED-6, pp. 1–5; January, 1959. Abstract, Proc. IRE, vol. 47, p. 611; April, 1959.)

621.382.333 1812

Transient Analysis of Junction Transistors—W. F. Gariano. (IRE Trans. on Electron Devices, vol. ED-6, pp. 90–100; January, 1959. Abstract, Proc. IRE, vol. 47, p. 612; April, 1959.)

621.382.333 1813

Effect of Transient Voltages on Transistors—H. C. Lin and W. F. Jordan, Jr. (IRE Trans. on Electron Devices, vol. ED-6, pp. 79–83; January, 1959. Abstract Proc. IRE, vol. 47, p. 612; April, 1959.)

621.382.333 1814

Influence of the Surface and Volume Recombination on α and the Collector Reverse Current in Alloy Junction Transistors—B. Ya. Mo͡izhes. (*Zh. tekh. Fiz.*, vol. 25, pp. 2402–2409; November, 1958.) Formulas are derived for the current gain α and collector reverse current in symmetrical and nonsymmetrical transistors, in presence of surface and volume recombination.

621.382.333 1815

A Modification of the Theory of the Variation of Junction-Transistor Current Gain with Operating Point and Frequency—A. W. Matz. (*J. Electronics Control*, vol. 7, pp. 133–152; August, 1959.). A modified solution of the continuity equation for minority-carrier flow is presented, with an extension to ac conditions. The observed maximum in the variation of common-base cutoff frequency with emitter current is explained. Experimental results are presented which show that transistor base widths may be smaller than is normally supposed.

621.382.333 1816

The Voltage Dependence of Reverse Currents in Alloy Transistors—A. Götzberger. (*Z. angew. Phys.*, vol. 11, pp. 6–9; January, 1959.) Investigations of transistor characteristics in relation to the punch-through effect.

621.382.333:621.318.57 1817

Transistor Bias Method Raises Breakdown Point—H. Somlyody. (*Electronics*, vol. 33, pp. 48–49; January 8, 1960.) The application of reverse-biasing technique to permit switching at voltages higher than the rated values.

621.382.333:621.318.57 1818

Germanium *p-n-p-n* Switches—I. A. Lesk. (IRE Trans. on Electron Devices, vol. ED-6, pp. 28–35; January, 1959. Abstract, Proc. IRE, vol. 47, p. 611; April, 1959.)

621.382.333.3 1819

On the Frequency Dependence of the Magnitude of Common-Emitter Current Gain of Graded-Base Transistors—M. B. Das and A. R. Boothroyd. (Proc. IRE, vol. 48, pp. 240–241; February, 1960.) The current gain is investigated theoretically and it is shown that it should fall by 6 db per octave increase in frequency, provided the effect of the emitter junction capacitance is small.

621.382.333.32 1820

A Double-Base Diode with Hook Mechanism—T. Tominaga, S. Kanai, and A. Sato. (*Rep. Elect. Commun. Lab., Japan*, vol. 7, pp. 133–137; May, 1959.) The device described has a thin layer of *p*-type Ge in the conductivity-modulated region of the original double-base diode. With this form of construction, the base-current power dissipation may be reduced to about 1/100th of its original value.

621.382.333.33 1821

Influence of Technology and of Diffusion on the Characteristics of a Drift-Type Transistor—J. Mercier. (*Onde élect.*, vol. 39, pp. 869–875 and pp. 897–907; November and December, 1959.) Characteristics of drift-type transistors are studied theoretically and an equivalent circuit is proposed. Parameters for the determination of performance are derived and used in the synthesis of a transistor element.

621.383.5:546.289:621.391.822 1822

Noise Phenomena in Photovoltaic Germanium Cells—M. Teboul. (*Compt. rend. acad. sci., Paris*, vol. 249, pp. 651–653; August 3, 1959.) The total noise at Ge photovoltaic junctions has been measured as a function of polarization and illumination and compared with calculated shot noise.

621.385.3.029.6 1823

Large-Signal Theory of U.H.F. Power Triodes—A. D. Sutherland. (IRE Trans. on Electron Devices, vol. ED-6, pp. 35–47; January, 1959. Abstract, Proc. IRE, vol. 47, pp. 611–612; April, 1959.)

621.385.6 1824

Independent Space Variables for Small-Signal Electron-Beam Analyses—D. L. Bobroff. (IRE Trans. on Electron Devices, vol. ED-6, pp. 68–78; January, 1959. Abstract, Proc. IRE, vol. 47, p. 612; April, 1959.)

621.385.6 1825

Electron-Beam Flow in Superimposed Periodic and Uniform Magnetic Fields—J. R. Anderson. (IRE Trans. on Electron Devices. vol, ED-6, pp. 101–105; January, 1959. Abstract, Proc. IRE, vol. 47, p. 612; April, 1959.)

621.385.6 1826

Theory of the Focusing of Sheet Beams in Periodic Fields—P. A. Sturrock. (*J. Electronics Control*, vol. 7, pp. 153–161; August, 1959.) Equations are given taking account of space charge, and stability and perveance are discussed. Any such focusing system is convergent if space charge is neglected. See 1827 below.

621.385.6 1827

Magnetic Deflection Focusing—P. A. Sturrock. (*J. Electronics Control*, vol. 7, pp. 162–168; August, 1959.) A scheme for focusing sheet beams by means of a periodic configuration of magnetic fields directed transverse to the beam is presented. Coupling between the beam and fast EM waves is possible.

621.385.6:537.533.1.08 1828

A Microwave Electron-Velocity Spectrograph—P. B. Wilson and E. L. Ginzton. (IRE Trans. on Electron Devices, vol. ED-6, pp. 64–68; January, 1959. Abstract, Proc. IRE, vol. 47, p. 612; April, 1959.)

621.385.623.5:621.396.62 1829

Reflex Klystrons as Receiver Amplifiers—K. Ishii. (*Electronics*, vol. 33, pp. 56–57; January 8, 1960.) An investigation of the performance of a Type-2K25 reflex klystron as an *X*-band amplifier is described.

621.385.624.2 1830

The Effect of Space Charge on Bunching in a Two-Cavity Klystron—T. G. Mihran. (IRE Trans. on Electron Devices, vol. ED-6, pp, 54–64; January, 1959. Abstract, Proc. IRE. vol. 47, p. 612; April, 1959.)

621.385.63 1831

Travelling-Wave-Tube Efficiency Degradation due to Power Absorbed in an Attenuator—C. K. Birdsall and C C. Johnson. (IRE Trans. on Electron Devices, vol. ED-6, pp. 6–9; January, 1959. Abstract, Proc. IRE, vol. 47, p. 611; April, 1959.)

621.385.63:621.317.74 1832

Measurement of Internal Reflections in Travelling-Wave Tubes using a Millimicrosecond Pulse Radar—D O. Melroy and H. T. Closson. (Proc. IRE, vol. 48, pp. 165–168; February, 1960.) A stroboscopic gating system produces a slowed-down facsimile of the recurrent pulses for display on a low-frequency CRO. Reflections with return losses of 40 db are easily observed.

621.385.63:621.375.9:621.372.44 1833

Waves on a Filamentary Electron Beam in a Transverse-Field Slow-Wave Circuit—A. E. Siegman. (*J. Appl. Phys.*, vol. 31, pp. 17–26; January, 1960.) The waves on a filamentary electron beam in a longitudinal dc magnetic field, and their interaction with a transverse-field slow-wave circuit, are studied in detail. The beam is found to carry four waves. This type of interaction may prove to be of practical importance, for instance in an electron-beam parametric amplifier.

621.385.63:621.375.9:621.372.44 1834

Some Possible Causes of Noise in Adler Tubes—C. P. Lea-Wilson, R. Adler, G. Hrbek, and G. Wade. (Proc. IRE, vol. 48, pp. 255–257; February, 1960.) Discussion of 321 of 1959 (Adler, Hrbek, and Wade) with reference to partition noise and noise caused by nonuniform electric field, by spread of axial velocities and by collisions between electrons and ions.

621.385.63.032.269 1835

A Gun and Focusing System for Crossed-Field Travelling-Wave Tubes—O. L. Hoch and D. A. Watkins. (IRE Trans. on Electron Devices, vol. ED-6, pp. 18–27; January, 1959. Abstract, Proc. IRE, vol. 47, p. 611; April, 1959.)

621.385.632 1836

The Design and Characteristics of a Megawatt Space Harmonic Travelling-Wave Tube—M. Chodorow, E. J. Nalos, S. P. Otsuka, and R. H. Pantell. (IRE Trans. on Electron Devices, vol. ED-6, pp. 48–53; January, 1959. Abstract, Proc. IRE, vol. 47, p. 612; April, 1959.)

621.385.632.12 1837

Strapped Bifilar Helices for High-Peak-Power Travelling-Wave Tubes—D. A. Watkins and D. G. Dow. (IRE Trans. on Electron Devices, vol. ED-6, pp. 106–114; January, 1959. Abstract, Proc. IRE, vol. 47, p. 612; April, 1959.)

621.385.64.032.213.13 1838

Dispenser-Cathode Magnetrons—G. A. Espersen. (IRE Trans. on Electron Devices, vol. ED-6, pp. 115–118; January, 1959. Abstract, Proc. IRE, vol. 47, p. 612; April, 1959.)

MISCELLANEOUS

621.38.004.6 1839

Reliability Analysis Techniques—C. A. Krohn. (Proc. IRE, vol. 48, pp. 179–192; February, 1960.) Recently evolved analytical techniques are effective in reducing failures and increasing reliability in electronic equipment.

ERRATUM

Abstract 1453 in the previous issue should read as follows—

Tuning and the Equivalent Circuit of Multiresonator Magnetrons—T. S. Chen. (*J. Electronics Control*, vol. 7, pp. 33–51; July, 1959.) An equivalent circuit is synthesized from the input-admittance function determined from the properties of the waveguide used to tune the magnetron. This circuit is used to calculate wide-band tuning characteristics, which agree with measurements for waveguide tuning systems with and without iris coupling.

Translations of Russian Technical Literature

Listed below is information on Russian technical literature in electronics and allied fields which is available in the U. S. in the English language. Further inquiries should be directed to the sources listed. In addition, general information on translation programs in the U. S. may be obtained from the Office of Science Information Service, National Science Foundation, Washington 25, D. C., and from the Office of Technical Services, U. S. Department of Commerce, Washington 25, D. C.

PUBLICATION	FREQUENCY	DESCRIPTION	SPONSOR	ORDER FROM:
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Automation and Remote Control (Avtomatika i Telemekhanika)	Monthly	Complete journal	National Science Foundation—MIT	Instrument Society of America 313 Sixth Ave., Pittsburgh 22, Pa
	Monthly	Abstracts only		Office of Technical Services U. S. Dept. of Commerce Washington 25, D. C.
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Radio Engineering (Radiotekhnika)	Monthly	Complete journal	National Science Foundation—MIT	Pergamon Institute 122 E. 55 St., New York 22, N. Y
	Monthly	Abstracts only		Office of Technical Services U. S. Dept. of Commerce Washington 25, D. C.
Radio Engineering and Electronics (Radiotekhnika i Elektronika)	Monthly	Complete journal	National Science Foundation—MIT	Pergamon Institute 122 E. 55 St., New York 22, N. Y
	Monthly	Abstracts only		Office of Technical Services U. S. Dept. of Commerce Washington 25, D. C.
Solid State Physics (Fizika Tverdogo Tela)	Monthly	Complete journal	National Science Foundation—AIP	American Institute of Physics 335 E. 45 St., New York 17, N. Y.
Telecommunications (Elekprosviaz')	Monthly	Complete journal	National Science Foundation—MIT	Pergamon Institute 122 E. 55 St., New York 22, N. Y
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Electronics Express	10/year	A digest: abstracts, summaries, annotations of various journals		International Physical Index, Inc 1909 Park Ave., New York 35, N. Y
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Structural imperfections, represented by this dislocation network in thin tantalum foil, determine the properties of a superconductor (electron transmission; 64,000x).

Superconductivity in Metals and Alloys

perconductivity—the absence of elec-cal resistance at very low temperatures s one of the most challenging of physical enomena. Its appeal is almost universal; application seems almost unlimited.

It has been suggested for use in friction-s bearings, motors, amplifiers, electro-gnets, gyroscopes and electron-beam paratus. IBM is concerned with still an-er possibility: the application of super-nductivity to computer devices.

Scientists at IBM Research have demon-ated, with a thin-film superconducting vice capable of switching in a few milli-croseconds, that computers of the future y be limited in their operating speeds ly by the speed of light. Whether or not a metal is a superconductor depends on many things: its structure, its valence, and the presence and position of alien atoms, missing atoms or electrons. The operation of superconducting devices depends upon the fact that a magnetic field will drive a superconductor into the normal (resistive) state.

A superconductor placed in a magnetic field develops a surface current which shields out any external magnetic field to a characteristic penetration depth. Since this penetration depth is comparable to the film thickness used in making superconducting devices, the penetration depth is an important property.

Superconducting alloys, with their inherent normal-state resistivity, offer promise for superior devices. Alloying can change the penetration depth, the electron density, and the ease by which a superconductor can be switched from one state to another.

Work is under way to outline the part played by impurities and structural defects in determining superconductivity. This work has already shown that microscopic homogeneity is a prerequisite of well-defined superconductive behavior. From such work may come devices that will make it possible to operate miniature computers at extremely high speeds.

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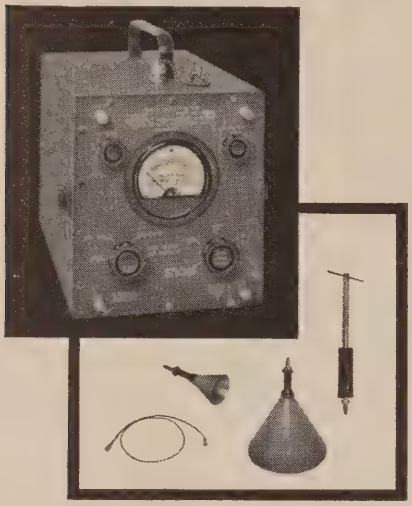

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- Direct reading of power density insures immediate awareness of hazardous areas.
- Broad frequency range and high accuracy permit universal application to mapping of high level RF fields from VHF to X-Band.
- Accurate built-in step attenuator provides capability of handling power densities over a dynamic range of 10,000 to 1.
- Three constant-gain calibrated probes permit direct reading in mw/cm² over the continuous frequency range from 200 to 10,000 MC.
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- Battery-powered, light-weight design permits complete portability.
- Convenient carrying case simplifies transportation of instrument.
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NEWS New Products

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(Continued from page 52A)

Rate Turntable

The T844 Rate Turntable developed by **Sterling Precision Corp.,** 17 Matinecock Ave., Port Washington, L. I., N. Y., is a simple, compact, portable test unit for mounting rate gyros, antennas, guidance assemblies and other components requiring imposition of constant rates-of-turn for

(Continued on page 114A)

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(Continued from page 112A)

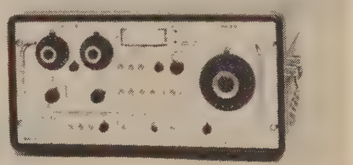
spot checks of performance. Although the basic unit provides for a single rate about a vertical axis, modified units can be furnished to provide multiple rates, tilting to polar or horizontal axes, or with servo drive.

For further information write for Catalog No. 152.

The Sterling T844 Rate turntable was displayed at the 1960 IRE Show.

Pulse And CW Signal Generator

New Pulse and CW Generator is now available from **Telonic Industries, Inc.**, Beech Grove, Ind. Designated as the Model PSX-1, the new unit produces video pulses, CW, pulsed CW, and audio modulated CW signals. The instrument is of value for the design and testing of precision IF amplifiers such as is used in radar systems, but also can serve in general laboratory applications.



The PSX-1 contains a complete video pulse generator section and an RF Section. Phantastrons and comparators produce video pulses with a repetition rate that is adjustable from 50 to 5000 cps. The width of each pulse is variable from 0.05 to 10 microseconds, with a rise-and-fall time of less than 0.02 microseconds. A front panel control allows the pulses to be advanced or retarded by 5 microseconds relative to the output synchronization signal, which consists of a 50-volt, one microsecond pulse with positive or negative polarity.

A CW oscillator and buffer circuits produce a signal that can be adjusted in frequency from 25 mc to 75 mc with an accuracy of 0.25 per cent. For CW operation, the output of the generator is 1 volt RMS into 50 volts, and is metered by a panel-front meter. This level is reduced by a toggle-switch attenuator, which provides 0–131 db attenuation in 1 db steps. A 0–10 db vernier attenuator is also provided for fine adjustments.

The CW signal can be modulated by video pulses, either by using the internal video-pulse circuit or by using an external source supplying pulses at a rate of from single pulses up to several megacycles. The output, under these conditions, is 10 to 12 volts, peak-to-peak. The "off" level between pulses is at least 65 db down from the pulse peak. Duty cycle is zero to 10%; pulse drop is less than 5%.

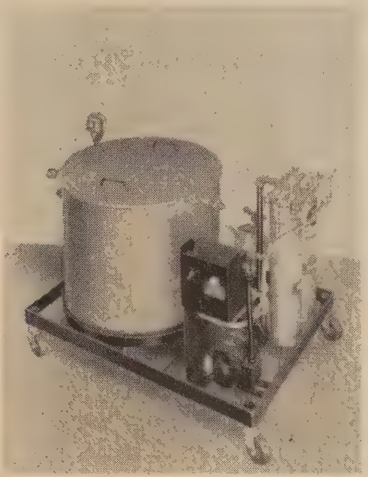
The CW signal may be audio modulated, using either an internal 1 kc oscillator or an external audio source, 50 to 5000 cps, 1 volt peak to peak into high impedance. The use of plate modulation of the buffer stage permits modulation from 0 to over 50%; the degree of modulation is metered on the instrument panel.

To simplify in production-line applications or wherever repetitive tests are to be conducted, eight preset positions can be adjusted to required pulse and widths.

For additional information contact the firm.

Rinse Water Repurification Equipment

Barnstead Still and Sterilizer Co., 2 Lanesville Terrace, Boston 31, Mass., announces the development of an ultra high purity rinse-water repurification unit. The unit is used in conjunction with ultrasonic cleaners; rinse tanks for transistors, diodes, and other small electronic parts; and any type of processing tank which must be kept supplied with pure water. The complete unit is mounted on a steel frame with wheels and is designed to roll under the counter containing the rinse chambers.

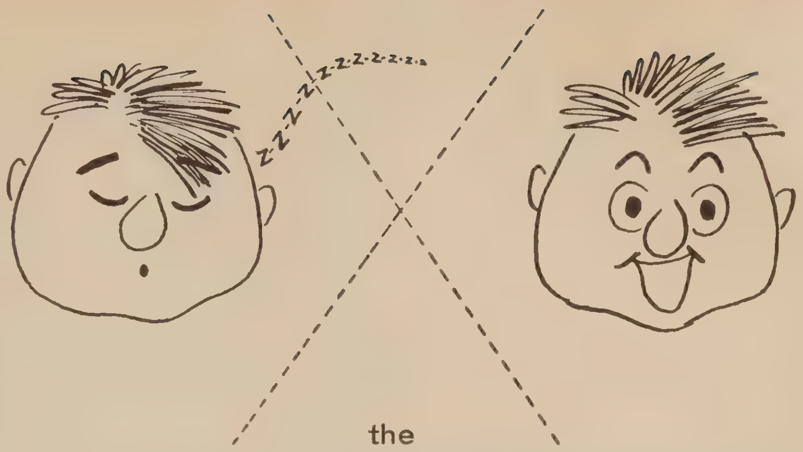


The contaminated rinse water is passed through an organic removal cartridge, through a mixed-resin cartridge to remove ionizable impurities, and through a submicron filter to remove submicroscopic particles to 0.45 microns. The repurified water has an electrical resistance of 10 to 18 megohms and is fed to the rinse tank to complete the cycle. Special heating elements and separate rinse chambers can be built into the unit, if required.

The unit consists of a Barnstead blocktin coated copper storage tank with a BD-22 Pressure Bantam® Demineralizer with disposable organic removal and mixed resin cartridges, an MF® Submicron Filter, and a stainless steel pump with starter. A Ventgard® on the storage tank protects the water in the tank from airborne contamination.

The components are available at various capacities so that specific customer requirements can be accommodated. All metal surfaces of this unit which contact

(Continued on page 116A)



the
importance
of being

BISTABLE

(especially if you're a transistor driving a relay)

If you've been toying with the idea of using a transistor circuit to drive a relay, here are some facts of life that may save you grief later on. The watchword is bistable operation — particularly with regard to the transistor.

What can make a mess of an otherwise compact, cool, low standby-power transistor is a driving circuit that leaves the little pill neither saturated nor cut off. The transistor is then very apt to become an unstable, variable gain amplifier, when it should be taking a firm stand in favor of either "on" or "off". The thing to do is design the input circuit properly so that *it* is responsible for the transfer from one stable state to the other. (The Schmitt trigger circuit is an excellent for instance.)

Once you've got the transistor operating as a flip-flop and not as an amplifier, a good relay to use is a bistable type. Then the relay simply monitors the condition of the driving circuit, and success is practically around the corner (maybe). Magnetic latching relays are just such switches — and they have the added advantage of needing no standby power. Naturally, we have all sorts and kinds which all carry the designation "Form Zzzzz."

You won't be completely out of the woods, however, until you've given some thought to (a) operating speed and (b) nature of the transistor load. As for the former, you may be on the verge of transistorizing a tube-relay circuit and wonder why, all else being equal, the relay will operate slower from transistors. Although the transistor will do all sorts of wonderful things on less power, one thing it won't do on less power is hurry the relay. The remedy is adding some external resistance and raising the source voltage — or lowering the impedance of the relay. As for the load the transistor must switch, it is well to remember that if it's inductive (and a relay coil is) and the energy cannot be safely dissipated in the transistor, you'd better find another outlet. The lack of "arc suppression" in transistor circuits, when needed, may not produce juicy blue sparks but the result is the same — quite rapidly.

Some of our application engineers are notoriously bistable, and depending on which state they are in when they hear from you, will undoubtedly send you either (+) circuit design ideas (based on the use of a Sigma relay) or (−) some zzzzz-inducing printed material on bistable applications. Zatisfaction guaranteed.

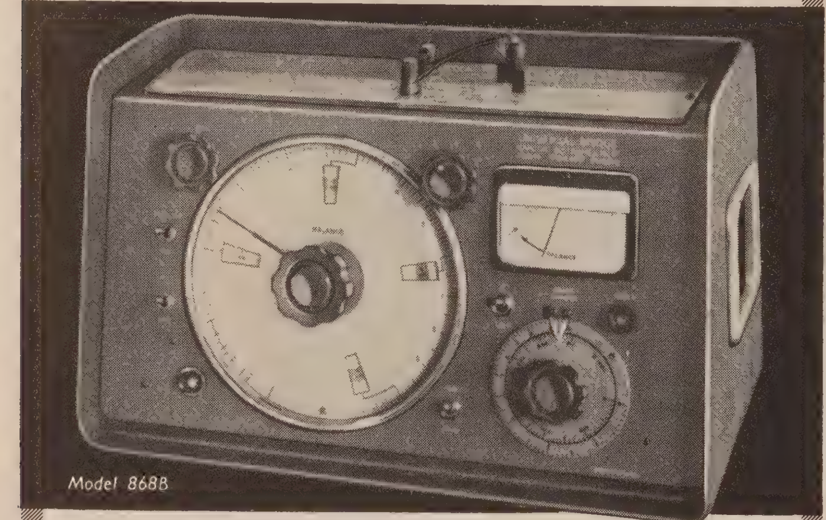
SIGMA

SIGMA INSTRUMENTS, INC.
94 Pearl Street, So. Braintree 85, Mass.

AN AFFILIATE OF THE FISHER-PIERCE CO. (Since 1939)

THE NEW MARCONI UNIVERSAL BRIDGE

Gives NEW Simplicity in LCR Measurements



L — 1 μH to 100 henrys
C — 1μμF to 100 μF
R — 0·1 ohm to 100 MΩ

•**Direct read-out with no multiplying factors, eliminates operator errors.** •**Model 868 B also has precision Q and tan δ (D) dials.** Inductance and capacitance are measured at 1 or 10 kc/s in an R-C ratio-arm bridge; resistance at d.c. in a Wheatstone bridge. The bridge detector gives positive indication of the direction of balance point even when far off-balance; as a result, components whose values are completely unknown can be evaluated in a few seconds with the minimum of searching. Detector a.g.c. eliminates the need for sensitivity controls.
Also available—**Low Capacitance Bridge Model 1342:** 0·002μμ F to 1,111μμ F; 3-terminal transformer ratio-arm bridge designed for precision measurement of extremely low capacitance.
For full details, write for leaflet D171.

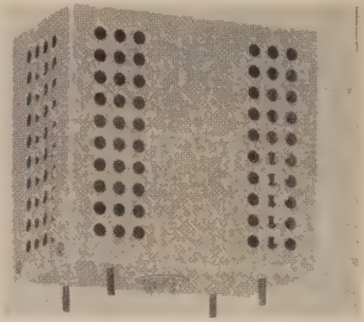
MARCONI INSTRUMENTS
111 CEDAR LANE • ENGLEWOOD • NEW JERSEY
TELEPHONE: LOwell 7-0607
Canada: Canadian Marconi Co · Marconi Building · 2442 Trenton Ave · Montreal 16
Marconi Instruments Ltd · St. Albans · Herts · England

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 115A)

the repurified water are of pure block tin. The manufacturer states that a PM-18 Purity Meter, which gives readings from 100,000 to 18,000,000 ohms and is compensated up to 212°F, is available as an optional item. For further information write maker.

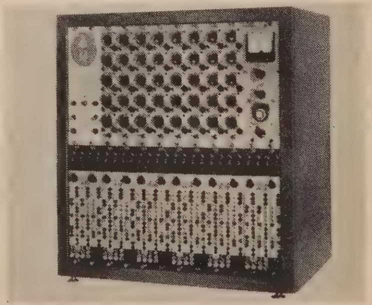
Power Supply



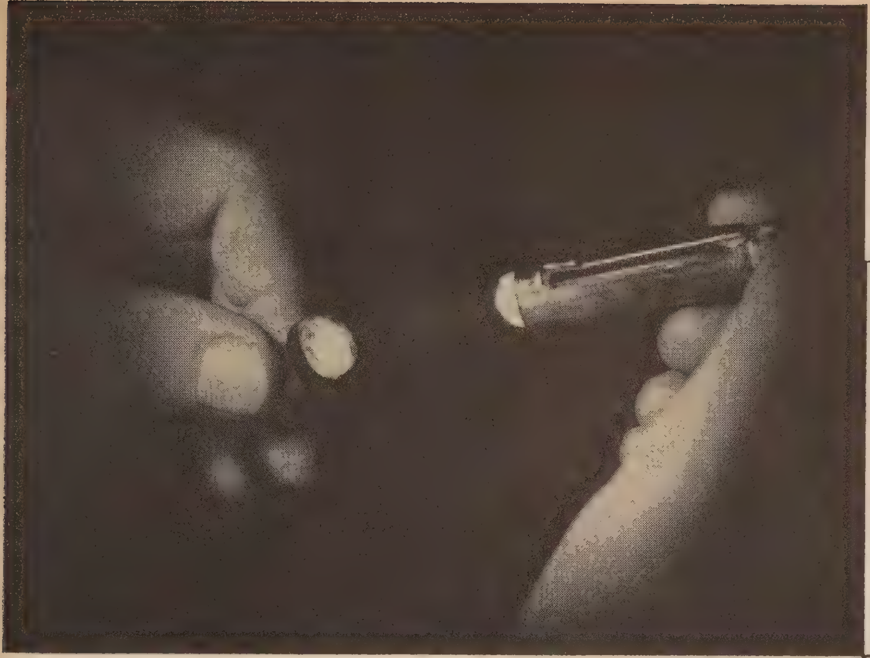
Harrison Laboratories, Inc., 45 Industrial Road, Berkeley Heights, N. J., announces the availability of its new Model 850 highly regulated transistor power supply. The unit is adjustable from 0 to 15 volts at any output current from 0 to 1 ampere. An octal plug is used for all input and output connections to the supply, including remote programming (333 ohms/volt) and remote sensing. Regulation is better than 3 millivolts; ripple, less than 500 microvolts for any combination of line or load. No voltage overshoot can occur at turn-off, and supply is fully protected for all overload conditions including a direct short across the output (no fuses employed). The unit measures $6\frac{1}{2}''$ L×$3\frac{7}{16}''$ W×6″ H. It is priced at $197.00. Rack Mounting Panels $3\frac{1}{2}''$ high are also available.

Table Top Analog Computer

A new "table-top" analog computer which solves mechanical, electrical, industrial and other problems which can be translated into mathematical data, is announced by **Applied Dynamics, Inc.,** a subsidiary of Bowmar Instrument Corp., P. O. Box 2068, Ann Arbor, Mich.



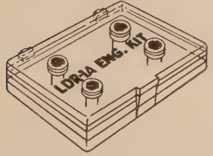
(Continued on page 118A)



LOOKING FOR THE ANSWER TO A CONTROL PROBLEM?

Spotlighted, above, is FXC's new Light Dependent Resistor, a "mighty mite" employed in the control of TV sets . . . organs . . . call systems . . . computers . . . automatic telephone exchanges . . . toys — and other applications calling for a change of circuit resistance as light intensity varies, even at relatively low levels. Smaller than a dime in diameter, the LDR has a resistance ratio in excess of 25,000 to 1 for a light intensity change from total darkness to 1,400 foot candles. Highly versatile, the LDR can be used with a light source to replace single, multi-pole or latching type relays or for gain limiting in amplifier circuits. It has an interminable service life and is exceptionally low in cost.

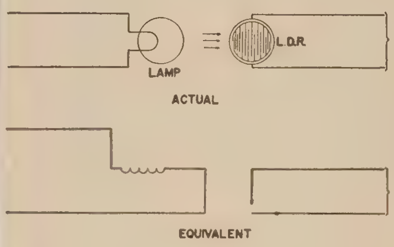
ORDER A LDR-1A ENGINEERING KIT FOR R&D


LDR-1A ENG. KIT

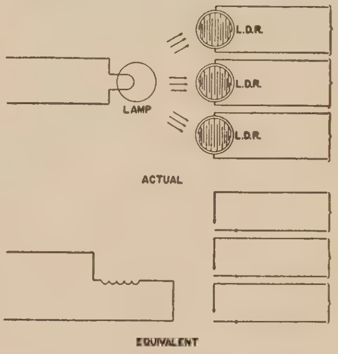
Includes complete technical data and 4 LDRs for only $10.00.

FERROXCUBE
CORPORATION OF AMERICA
50 East Bridge Street, Saugerties, New York

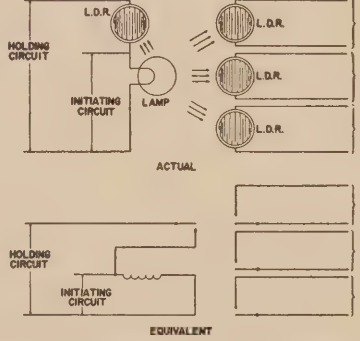
4 WAYS TO USE LDRs WITH A LIGHT SOURCE


LAMP
L.D.R.
ACTUAL
EQUIVALENT

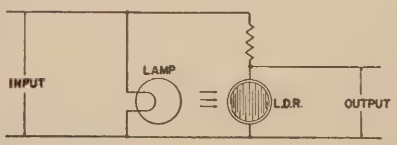
(1) As a single pole relay.


L.D.R.
L.D.R.
L.D.R.
LAMP
ACTUAL
EQUIVALENT

(2) As a multi-pole relay.


L.D.R.
HOLDING CIRCUIT
INITIATING CIRCUIT
LAMP
L.D.R.
L.D.R.
L.D.R.
ACTUAL
HOLDING CIRCUIT
INITIATING CIRCUIT
EQUIVALENT

(3) As a latching type relay.


INPUT
LAMP
L.D.R.
OUTPUT

(4) As a gain limiting control.

IMPULSE

A DIGEST OF NEW DEVELOPMENTS IN ELECTRONICS AND AUTOMATION

PUBLISHED BY ROME CABLE DIV. OF ALCOA, ROME, N. Y.
PIONEERS IN INSTRUMENTATION CABLE ENGINEERING

PATENT-LY ABSURD appears to be the way the House Space Committee feels about patent procedures currently in effect with NASA contractors. Provisions of the 1958 law establishing NASA spelled out restrictions on patent advantages when such came about through government-financed research. Complications arose when an individual firm also had contracts with the Pentagon, since these permit keeping patent rights. A new amendment reverses the original policy, even allows NASA to change provisions in existing contracts.

WHY NYET? Two items of interest to electronic men in reference to Russian developments: First, a Russian engineer reports at length in a Soviet periodical that lack of electronic standardization, particularly in coupling devices, is a serious problem. Second, *we* have put a technique called *predictive analysis* to work with a computer in order to simplify English translations of Russian scientific articles. Up to now the computer could produce only rough word-for-word translations. With predictive analysis, the machine approaches a sentence as a human does. As a result, the output contains not only the English translation, but also the grammatical relation of each word.

FM ON THE MOVE. One industry spokesman predicts that FM sales will hit 4 million units in 1963, including a million sets for use in automobiles. Still to be resolved is the big question of stereophonic broadcasting.

INTEREST in electric cars seems definitely on the increase. Considerable attention to fuel cells (a comprehensive book is almost ready for release), introduction of a silicon solar-cell panel, and advances in printed motor armatures all point to big things in the future.

CABLEMAN'S CORNER. To help you in replacing or reordering cable, it has become standard practice for most cable manufacturers to identify their cable in one of several ways. These include the stamping of solid conductors, the inclusion of marker threads or tapes within the cable structure, and surface printing or molding the insulations or jackets. Of these methods, the use of marker threads or tapes is the most popular. Manufacturers of Underwriters-labeled products are assigned specific colors for their marker threads, and most manufacturers extend the use of these same threads in other cable products whenever it is practical. Other information appearing on marker tapes often includes unit length markings and the date that the cable was manufactured. Phone Rome 3000, or write: Rome Cable Division of Alcoa, Department 400-A, Rome, New York.

These news items represent a digest of information found in many of the publications and periodicals of the electronics industry or related industries. They appear in brief here for easy and concentrated reading. Further information on each can be found in the original source material. Sources will be forwarded on request. ⑲

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 116A)

Basically it may contain from 4 to 32 amplifiers, depending upon applications. Modules may be used to expand the AD-1 to a full complement of 64 amplifiers. Four amplifiers are contained in each plug-in module. ADI states that the approximate $3000 price is for a complete 12-amplifier unit.

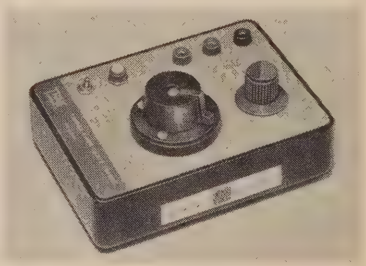
All integrating capacitors, matched feedback resistors and summing resistors are built into the computer, a factor said to simplify operation, improve accuracy, eliminate the need for external components, and reduce the number of patch cords required.

The instrument utilizes a basic reference of 100 volts, made possible through vacuum tube design. Circuits are less delicate and less sensitive to spurious coupling and provide more reliable and more easily read answers.

The entire computer is modular in design and expandable in all its assemblies to provide economical, non-obsolescent usage at the office, laboratory, department or small plant levels.

Additional details are available from the firm.

Tunnel Diode Curve Tracer



The TRAK® Tunnel Diode Curve Tracer available from **Trak Electronics Co., Div.** of CGS, 48 Danbury Rd., Wilton, Conn., is an instrument for use with a laboratory oscilloscope which presents the current-voltage characteristic of tunnel diodes throughout the negative resistance region. The instrument is provided with a clip for receiving both of the diode packages currently being manufactured.

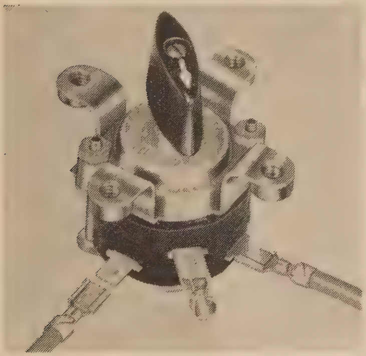
A four-position range switch adjusts the scale factor of the transformation from current to voltage for the vertical deflection signal and simultaneously changes the shunt impedance on the diode. The available range exceeds that necessary for testing currently available models in anticipation of improved diodes with different characteristics. The accuracy of conversion from current to voltage is ±1%; otherwise the accuracy in use depends upon the accuracy with which the deflection of the oscilloscope is calibrated.

A second knob controls the horizontal sweep voltage from zero to $1\frac{1}{2}$ volts.

Stray inductances are so small that diodes capable of oscillating at 2 kmc are adequately damped. The source impedance is approximately one ohm and the curve presented on the oscilloscope is continuous throughout the negative resistance region.

The unit is housed in an epoxy container measuring $1\frac{3}{4} \times 4 \times 5\frac{1}{4}$ inches and is operated from a 115 volt, 60 cps source. Price is $57.50 f.o.b. Wilton.

Rotary Power Switch



To permit rapid wiring with snap-on connectors, the 10-ampere ESCO Type P Rotary Snap Switch is now available from **Electro Switch Corp.,** King Ave., Weymouth, Boston 88, Mass., with male quick-connect terminals. These terminals, which are integral with the stationary contacts, can be furnished on any of the side-connected switches having either make-before-break or break-before-make contacts.

Detailed information is available from E. J. Dennehy, at the firm.

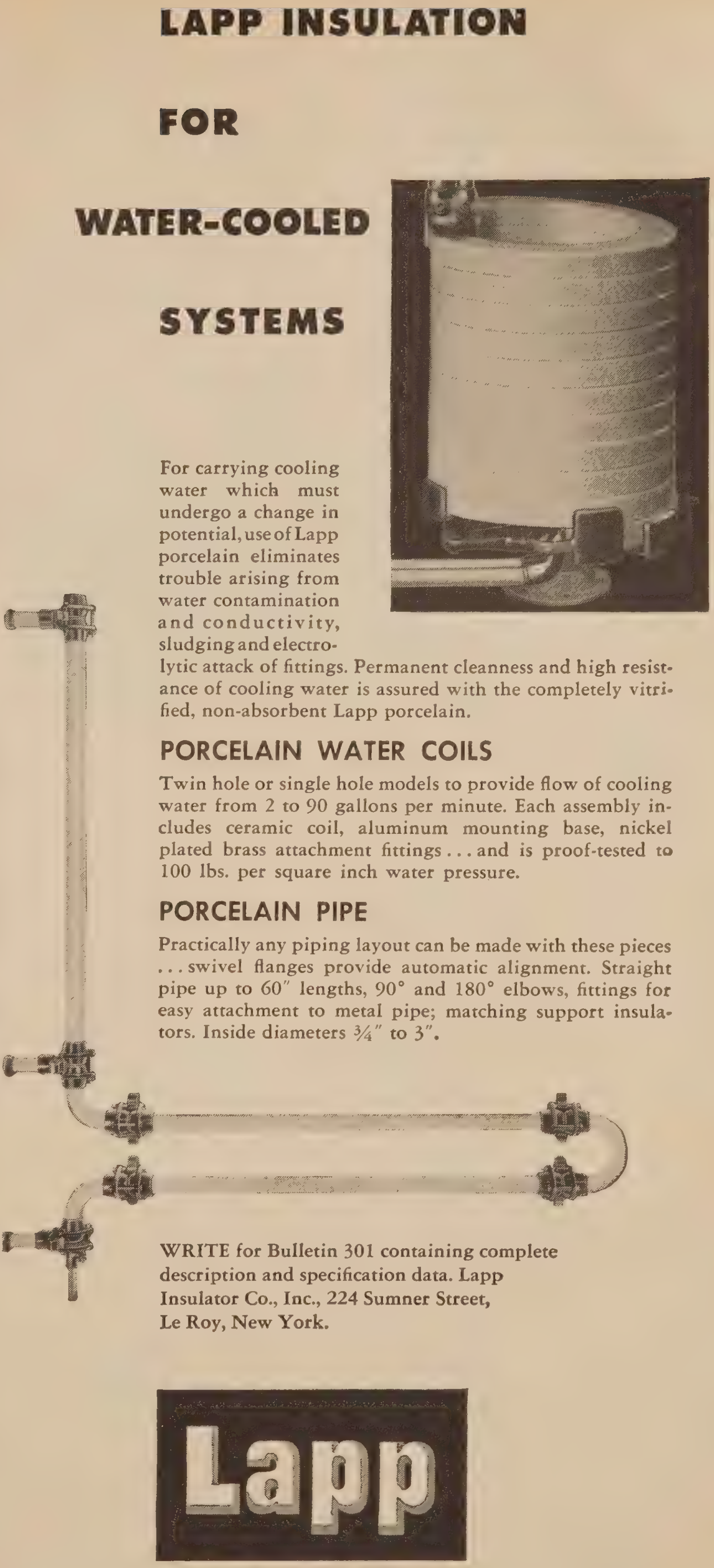
Solid State Counter-Timer

The Model 1039 10 mc counter-timer fully transistorized and designed for both commercial and military application is available from **Systron Corp.,** 950 Galindo St., Concord, Calif. It provides measurements of frequencies from 0 to 10 mc, time intervals and periods from 0.3 μsec to 10^8 sec, frequency ratios to 10^8 and phase measurements direct to 0.1°.

SYSTRON
12468260

The price is $2900. This is thought to be the lowest priced solid state 10 mc counter on the market and yet provides exclusive features of Nixie In-Line Readout, 3 dc amplifiers all with 1 megohm input impedance—0.1 volt rms sensitivity, and a panel height of $5\frac{1}{4}$ inches. With the complete elimination of vacuum tubes the power consumption is 50 watts and plug-in printed circuit boards are used to make this unit ideal for production testing where reliability and ease of maintenance are prime requisites. Delivery is 30 to 60 days. Complete specifications available.

(Continued on page 120A)


LAPP INSULATION FOR WATER-COOLED SYSTEMS

For carrying cooling water which must undergo a change in potential, use of Lapp porcelain eliminates trouble arising from water contamination and conductivity, sludging and electrolytic attack of fittings. Permanent cleanness and high resistance of cooling water is assured with the completely vitrified, non-absorbent Lapp porcelain.

PORCELAIN WATER COILS

Twin hole or single hole models to provide flow of cooling water from 2 to 90 gallons per minute. Each assembly includes ceramic coil, aluminum mounting base, nickel plated brass attachment fittings . . . and is proof-tested to 100 lbs. per square inch water pressure.

PORCELAIN PIPE

Practically any piping layout can be made with these pieces . . . swivel flanges provide automatic alignment. Straight pipe up to 60″ lengths, 90° and 180° elbows, fittings for easy attachment to metal pipe; matching support insulators. Inside diameters ¾″ to 3″.

WRITE for Bulletin 301 containing complete description and specification data. Lapp Insulator Co., Inc., 224 Sumner Street, Le Roy, New York.

Lapp

MORE RELIABILITY and BETTER PERFORMANCE with

FREED QUALITY

HERMETICALLY SEALED, MIL-T-27A PULSE TRANSFORMERS

- Maximum power efficiency and optimum pulse performance.
- For use in blocking oscillator, interstage coupling and low level output circuits.
- Ruggedized construction — Grade 4.
- Series or parallel connection of windings for optimum turns ratio.

DM-01 DM- 8 DM-20 DM-18

Cat. No.	MIL Type	Pulse Voltage Kilovolts	Char. Imp. Ohms
MPT- 1	TF4RX35YY	0.25/0.25/0.25	250
MPT- 2	TF4RX35YY	0.25/0.25	250
MPT- 3	TF4RX35YY	0.5/0.5/0.5	250
MPT- 4	TF4RX35YY	0.5/0.5	250
MPT- 5	TF4RX35YY	0.5/0.5/0.5	500
MPT- 6	TF4RX35YY	0.5/0.5	500
MPT- 7	TF4RX35YY	0.7/0.7/0.7	200
MPT- 8	TF4RX35YY	0.7/0.7	200
MPT- 9	TF4RX35YY	1.0/1.0/1.0	200
MPT-10	TF4RX35YY	1.0/1.0	200
MPT-11	TF4RX35YY	1.0/1.0/1.0	500
MPT-12	TF4RX35YY	0.15/0.15/0.3/0.3	700

Ruggedized, MIL STANDARD POWER & FILAMENT TRANSFORMERS

Primary 105/115/125 V 50-60~

Cat. No.	Appl.	MIL Std.	MIL Type
MGP 1	Plate & Fil.	90026	TF4RX03HA001
MGP 2	Plate & Fil.	90027	TF4RX03JB002
MGP 3	Plate & Fil.	90028	TF4RX03KB006
MGP 4	Plate & Fil.	90029	TF4RX03LB003
MGP 5	Plate & Fil.	90030	TF4RX03MB004
MGP 6	Plate	90031	TF4RX02KB001
MGP 7	Plate	90032	TF4RX02LB002
MGP 8	Plate	90036	TF4RX02NB003
MGF 1	Filament	90016	TF4RX01EB002
MGF 2	Filament	90017	TF4RX01GB003
MGF 3	Filament	90018	TF4RX01FB004
MGF 4	Filament	90019	TF4RX01HB005
MGF 5	Filament	90020	TF4RX01FB006
MGF 6	Filament	90021	TF4RX01GB007
MGF 7	Filament	90022	TF4RX01JB008
MGF 8	Filament	90023	TF4RX01KB009
MGF 9	Filament	90024	TF4RX01JB012
MGF 10	Filament	90025	TF4RX01KB013

Ruggedized, MIL STANDARD AUDIO TRANSFORMERS

Cat. No.	Imped. level—ohms	Appl.	MIL Std.	MIL Type
MGA 1	Pri. 10,000 C.T. Sec. 90,000 Split & C.T.	Interstage	90000	TF4RX15AJ001
MGA 2	Pri. 600 Split Sec. 4, 8, 16	Matching	90001	TF4RX16AJ002
MGA 3	Pri. 600 Split Sec. 135,000 C.T.	Input	90002	TF4RX10AJ001
MGA 4	Pri. 600 Split Sec. 600 Split	Matching	90003	TF4RX16AJ001
MGA 5	Pri. 7,600 Tap @ 4,800 Sec. 600 Split	Output	90004	TF4RX13AJ001
MGA 6	Pri. 7,600 Tap @ 4,800 Sec. 4, 8, 16	Output	90005	TF4RX13AJ002
MGA 7	Pri. 15,000 C.T. Sec. 600 Split	Output	90006	TF4RX13AJ003
MGA 8	Pri. 24,000 C.T. Sec. 600 Split	Output	90007	TF4RX13AJ004
MGA 9	Pri. 60,000 C.T. Sec. 600 Split	Output	90008	TF4RX13AJ005

FREED TRANSFORMER CO., INC.

NEWS New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 119A)

Frequency Calibrator

The Haddam Manufacturing Co., Inc., office at 30 Rockefeller Plaza, New York 20, N. Y., plant at Route 9, Haddam, Conn., announces a highly stable Secondary Frequency Standard in a portable transport case. Known as the Bailey ZEROBEAT, this instrument is particularly useful in the "netting in" of mobile FM communication systems. Simplified design makes it possible to check and correct the frequency of both receiver and transmitter of a given station in a matter of seconds.

A highly stabilized 100 kc crystal oscillator controls harmonic generators and multivibrators to produce signals in the HF, VHF, and UHF ranges. Output signals of sufficient amplitude are available to saturate the limiter of receivers at all assigned frequencies in the 30–50 mc, 150–170 mc, and 460 mc bands of the new split channel, narrow band mobile communications channels. Accuracy in field service is 2 parts per million (±.0002%) from 10°F to +125°F. In addition to FM applications, the Zerobeat will function in the normal manner of any secondary frequency standard and may be used as such. Audio output connection allows visual or audible zerobeating of signal being measured.

The instrument, packaged in a portable carrying case, measures $18\frac{7}{8}''$ wide, $11\frac{1}{8}''$ high, and $6\frac{1}{4}''$ deep, including removable cover; and weighs approximately 18 pounds. Standard 19″ wide panel mounting is available for use in rack or cabinet. Price is $495.00.

Clear Sintered Glass

The full range of sintered glasses used for glass-to-metal sealing can now be produced with a clarity that permits visual inspection of the seal.

Called Clearform, the materials are made by a new technique developed by **Corning Glass Works, Ceramics Dept., Electrical Prods., Div.,** Corning, N. Y.

Clearform was shown for the first time at the Radio Engineering Show in New York City.

Seals made with these materials can be readily checked for quality, according to the manufacturer, by observing the seal through the glass.

To keep informed . . . Keep a file . . . with

SOLID STATE ABSTRACTS ON CARDS

3 x 5 index cards with abstracts of the important articles from more than 250 technical journals published throughout the world. Also U.S. patents, conference papers, new product releases.

Thousands of abstract cards, hundreds of guide cards.

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For Computer Engineers . . .

COMPUTER ABSTRACTS ON CARDS

For further information write for our descriptive literature

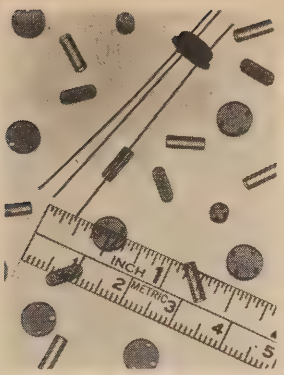
CAMBRIDGE COMMUNICATIONS CORPORATION
238 MAIN ST., CAMBRIDGE 42, MASS.
KIRKLAND 7-1997

A·S

Antenna Systems, Inc., is devoted exclusively to the design, fabrication and installation of antenna systems in the fields of scatter communications, missile tracking, space tracking, radar and surveillance, radio astronomy, and special antenna products.

We invite your inquiry, whatever your antenna problem may be. Write for our folder.

ANTENNA SYSTEMS INC.
HINGHAM, MASS.



Use of the materials provides a precise volume of glass in intricate shapes for critical sealing applications. The clear materials permit measurement of the stress patterns in the seal.

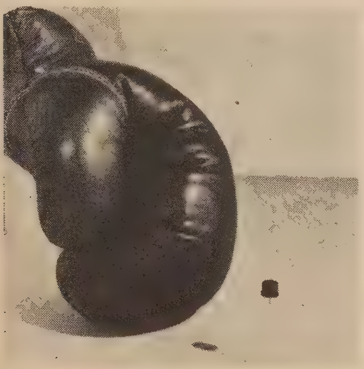
The sintered glasses are made by pressing small glass particles to shape and then firing the piece at high temperature. The particles are consolidated by fusion into a non-porous, vacuum-tight structure.

Clearform can be produced in a variety of shapes and sizes with extremely close tolerances. These materials retain the thermal endurance, corrosion resistance and dielectric strength of the parent glass.

Corning said the clear materials can be made from the glass compositions now used for sealing Dumet, Kovar, molybdenum, platinum and other metals.

Switching Transistor

A high-speed switching transistor, capable of surviving shocks in excess of 20,000 times the acceleration of gravity, has been developed by **Sylvania Electric Products Inc.**, a subsidiary of **General Telephone & Electronics Corp.**, Woburn, Mass.



Designed for use in telemetered torpedoes, projectile fuzes, electronically guided high-impact missiles, and other applications where extreme acceleration shocks are encountered, the new Sylvania transistor is capable of operation "during and after guaranteed minimum acceleration of 20,000Gs."

Designated 2N1473, the new Sylvania Transistor, a germanium alloy junction type, has "survived shock tests up to 140,000Gs," Dr. Pietempol stated. It will also perform critical switching functions in computers at currents up to 400 ma, he added.

Absolute maximum ratings for the 2N1473 are 40 volts Vcbo, 20 volts Vceo,

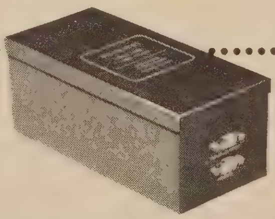
(Continued on page 122A)

DEEP THOUGHTS FROM DEEP DOMES / NO. 5 OF A SERIES

Digby on Poverty

Admiral of the Fleet Sir Roger Twigger-Digby (1837-1899), noted as the first man ever launched from a cruiser in a Montgolfier balloon, said it concisely: *"Money talks? Poverty talks, too, but nobody wants to hear what it has to say."* Sir Roger, naval aviation's first (and last) hot-airman, should have lived to see HOOVER ELECTRONICS COMPANY'S approach to the problems of the poor.

We at HOOVER keep a specially sympathetic ear for those with budget problems . . . constantly striving to provide the *ultimate* in electronics systems, design, and shelf items at a *reasonable* price. The definition of "reasonable" is, of course, as flexible as a tomcat's morals, but the definition of HOOVER ELECTRONICS is still as rigid as a Guardman's back. Budget trouble? We take it in stride . . . and it's always a stride forward.

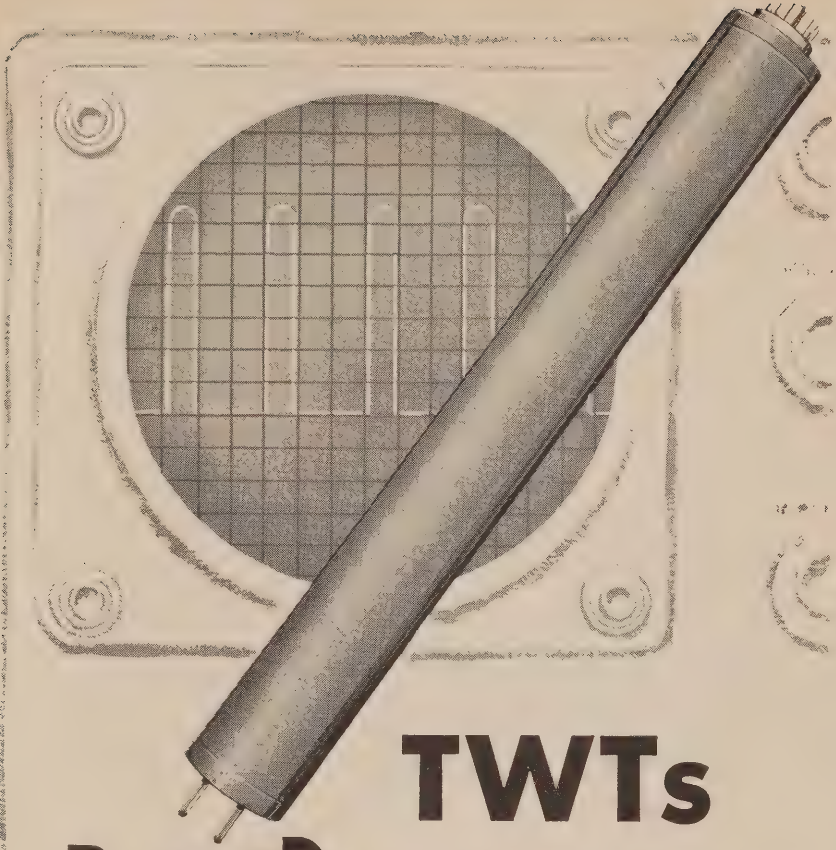


Here's an example: VERNITEL, the heart of the HOOVER system that improves FM/FM telemetering systems by a whole order of magnitude, yet saves money by prolonging their lives, in as humanitarian a gesture as you're likely to find in a day's ride. Write for complete specification sheets.

HOOVER
ELECTRONICS COMPANY
SUBSIDIARY OF THE HOOVER COMPANY

110 WEST TIMONIUM ROAD • TIMONIUM, MARYLAND

Los Angeles, California
Field Liaison Engineers



TWTs

PULSED FOR POWER

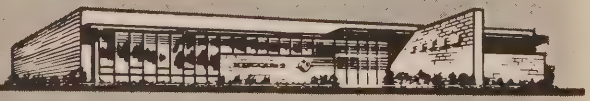
Huggins Pulsed Amplifiers are designed to provide more power on their broad frequency band. Normally operating with a 10% duty cycle, they produce a peak power 10 times their CW output. Small signal and saturation gain are increased by as much as 10 DB.

Huggins Laboratories produces solenoid and PPM focused pulsed amplifiers:*

Freq.	Solenoid	PPM	CW	Pulsed
2-4 kmc	PA-4	PA-6	100 mw	1 watt
2-4 kmc	PA-3	PA-10	1 watt	10 watt
4-8	PA-7	PA-8	100 mw	1 watt
8-11	PA-1	PA-9	100 mw	1 watt
8.2-12.4	PA-5		50 mw	.5 watt

**Periodic Permanent Magnet*

HUGGINS LABORATORIES, INC.



manufacture
development
engineering
design
research

999 East Arques Avenue · Sunnyvale, California

REgent 6-9330

(Continued from page 121A)

15 volts Vebo, 400 ma Ic, −50°C to +75°C storage temperature, +75°C junction temperature.

Sylvania's Semiconductor Division has its headquarters plant at Woburn, a manufacturing plant at Hillsboro, N. H., and a development laboratory at Northlake, Ill.

Transistorized Input Scanner

A new series of input scanners, transistorized for highly reliable operation in automatic data logging systems, has been announced by **Non-Linear Systems, Inc.,** Del Mar, Calif.

Interconnecting an NLS input scanner, NLS digital measuring instrument and data recorder produced an automatic system for sequentially scanning, measuring and recording up to 200 separate inputs. NLS Voltage Comparators can be connected to a similar system for go/no-go testing.

The three new, standard input scanners are the Model 260 which sequentially connects up to 100 single-pole channels to the digital voltmeter for measurement, the Model 261 for 200 single-pole channels, and the Model 262 for 100 double-pole channels. All three provide channel identification for the data recorder.

The new scanners are transistorized companions to transistorized digital voltmeters, ratiometers and ohmmeters. All logic functions in the new units are performed by semi-conductors instead of relays. Heavy-duty stepping switches with gold-plated contacts and extremely high insulation resistance are used.

The scanners can be controlled remotely, or manually by use of front panel controls. Channel identification is automatically recorded on the data printer and displayed in the readout by one-inch high, illuminated numerals. The readout is the NLS snap-out type for the fast bulb servicing without the use of tools or soldering. Transistor circuits are mounted on epoxy-fiberglass plug-in circuit boards for easy fast servicing.

For complete information, contact the firm.

Escon, New Subsidiary Of Glass-Tite

Glass-Tite Industries, Inc. 88 Spectacle St., Providence, R. I. has set up a new subsidiary, ESCON, Inc., according to Ralph Papitto, Glass-Tite founder and president. Frank Brakenwagen, formerly with Metals & Controls Corp., will have charge of the ESCON operation.

Glass-Tite Industries is a manufacturer of hermetic seals and terminals for semi-conductors, relays, crystal bases and custom applications in the electronics industry. ESCON, Inc. will specialize in such projects as manufacture of connectors for missiles, aircraft, computer and other electronic systems, with emphasis on custom applications.

(Continued on page 139A)

n essential source f information for lesigners, technicians nd research workers n electronics

ILLUSTRATED ARE SUBJECT HEADINGS
FROM THE APRIL 1960 ISSUE

AMMONIA MASER OSCILLATORS

JUNCTION TRANSISTOR CIRCUITS

SEMICONDUCTORS

RING-TYPE TRANSMISSION-LINE NETWORKS

RECTIFIER MODULATORS

ELLIPTIC WAVEGUIDE WINDOWS

STANDARD-FREQUENCY TRANSMISSIONS

ABSTRACTS AND REFERENCES

ELECTRONIC TECHNOLOGY—in step with the accelerated expansion and diversification of electronics—embraces the subject with new thoroughness.

Here you will find full coverage of the entire field; detailed up-to-the-minute descriptions of all classes of apparatus embodying thermionic and semi-conducting devices; regular articles by leading authorities on telecommunications, radio, radar, television, computers, control apparatus, measuring equipment. ELECTRONIC TECHNOLOGY, which is the new title of Electronic & Radio Engineer, is the magazine for all concerned with design, development and industrial application.

With extended and improved content it offers the ultimate in technical journalism—to keep you abreast of progress in this virile industry.

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Electronic technology

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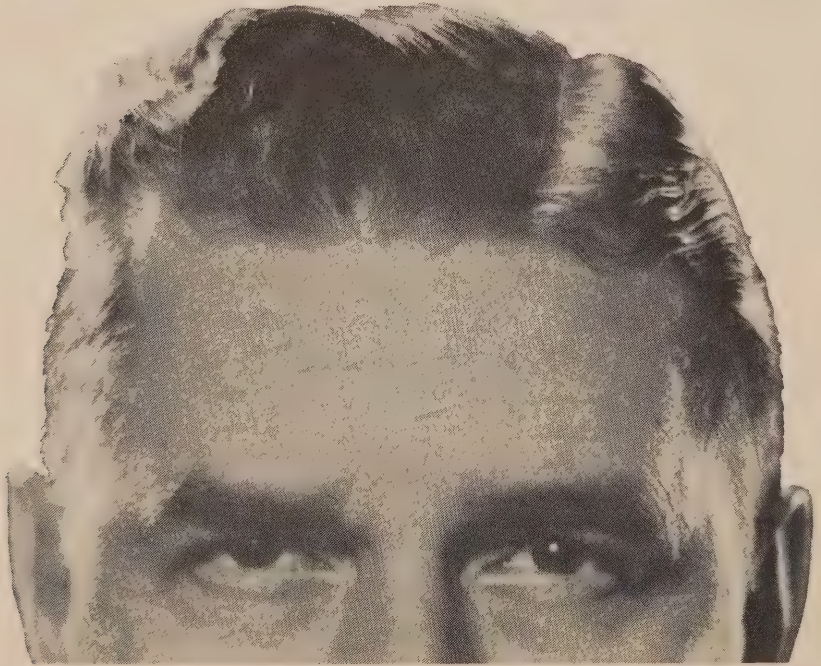
PRO.IRE

Problems $\stackrel{+}{\times}\div$? For The Inquiring Mind !

In the final analysis, it's the product a company manufactures which determines the atmosphere surrounding an Electronic Engineer. If the company is dull and prosaic . . . endlessly stamping out millions of identical items . . . then it almost certainly follows that so-called engineering will be mundane and uninteresting. ☐ On the other hand, it's quite possible to be involved in work that's so far out it is insecure. Take missiles versus aircraft, for example. It appears now that missiles will inherit the mantle . . . **but which ones?** Yours might be a winner and it might not. ☐ Ours is one of the select few companies which offers stability plus the excitement of almost infinite variety. You see, we are completely occupied with unique electronic engineering problems relating to the development and production of thousands of different extremely precise devices. We're about as far as you can get from an assembly line, operating as we do on a special project basis for the nuclear weapons program. This makes BENDIX a fascinating place to work. Our long-term prime contract with the Atomic Energy Commission makes it a **secure** place to work. ☐ Our wonderful community adds the pleasures of comfortable suburban living to the rewards of a basically important line of endeavor. Our climate and terrain are much like those in Virginia. We have four mild but readily-identifiable seasons in a rolling, wooded landscape which is famous for its beauty. Housing is comfortable, inexpensive and close to work. We have excellent schools and universities, art galleries, a symphony orchestra and major league baseball. ☐ You'll like BENDIX and you'll like Kansas City. We guarantee it. Write Tim Tillman, Technical Placement Supervisor, Box 303-PH, Kansas City 41, Missouri. He will supply you with all details.

THE Bendix CORPORATION
KANSAS CITY DIVISION



Positions Open

The following positions of interest to IRE members have been reported as open. Apply in writing, addressing reply to company mentioned or to Box No. . . . .

The Institute reserves the right to refuse any announcement without giving a reason for the refusal.

Proceedings of the IRE
1 East 79th St., New York 21, N.Y.

SENIOR ELECTRICAL ENGINEER

E.E. degree and 8-10 years experience including experience in electronics. Interesting work in conjunction with a nuclear physics research program. Benefits include a reduced tuition rate for the employee and free tuition for children of employees with 5 or more years of service. If interested, send complete resume, including salary expectations to J. R. Whitley, Employment Supervisor, University of Rochester, 260 Crittenden Blvd., Rochester 20, N.Y.

MEDICAL ELECTRONICS

Biophysical Electronics, Inc. devotes its efforts to the design and manufacture of instruments assisting the physician, psychologist, and research scientist to meet the challenge of preserving and extending life. Positions are open for: Senior Transistor Circuit Designer, Sales and Office Manager and experienced Electronic Technician. Submit resume, availability and salary requirements in first letter to Biophysical Electronics, Inc., New Hope, Pa.

ELECTRONICS ENGINEER OR PHYSICIST

High qualifications and varied experience, particularly in control, rf or nuclear electronics. Appointment as Assistant Professor at $7,000-$8,900 or as Associate Professor at $9,000-$11,700, or to non-academic position at equivalent salaries. To supervise construction of a spiral-ridge cyclotron to produce 50 Mev protons. Apply to Dr. B. G. Whitmore, Physics Dept., University of Manitoba, Winnipeg 9, Manitoba, Canada.

ENGINEER

To assist in construction of new cyclotron installation. Permanent position. Experience in building and maintaining scientific apparatus essential. Specific experience with cyclotrons desirable. Salary dependent on qualifications and experience. Apply to Dr. B. G. Whitmore, Physics Dept., University of Manitoba, Winnipeg 9, Manitoba, Canada.

TEACHING-RESEARCH, ELECTRICAL ENGINEERS

Expanding university program provides unusual opportunities for positions combining teaching and research. Rank and salary open. Teaching in all E.E. fields. Research primarily in microwave electronics. Apply: Dean E. C. Easton, Rutgers University, New Brunswick, New Jersey.

ELECTRONIC ENGINEERS

Positions open to Electronic Engineers teaching lecture and laboratory courses in a rapidly growing 4 year college. A background of servomechanisms, circuit analysis, microwaves, and/or transistors is desired. Applications desired from both academic and industrial personnel. Write, Harold P. Skamser, Dean of Engineering, Calif. State Polytechnic College, Kellog-Voorhis Campus, Pomona, Calif.

(Continued on page 128A)

Demanding Assignments for
Senior Staff Members at

SYLVANIA RSL

Reconnaissance Systems Laboratory on the
SAN FRANCISCO PENINSULA

SENIOR SYSTEMS ENGINEERS

System management responsibility for new programs at Sylvania's Reconnaissance Systems Laboratory offers the broad spectrum of challenging problems involved in large reconnaissance systems. A minimum of 10 years experience is required in progressive assignments leading to and including systems analysis, determination of functional systems requirements and synthesis and integration of subsystems with over-all program requiring knowledge of the capabilities and limitations of techniques and components. Should have background in analysis and synthesis of HF and VHF communication systems employing a variety of modulation techniques and/or digital data handling and automatic control systems.

SENIOR DESIGN ENGINEERS

The design groups in RSL have openings for experienced engineers with six or more years of design and development background in one or more of these areas: communications receivers, digital tuning, RF distribution, DF equipment, magnetic tape recorders, teletype equipment, dynamic displays, demodulators, data transmission, data converters and computers. Opportunities for both technical specialists and supervisors.

THE REWARDS

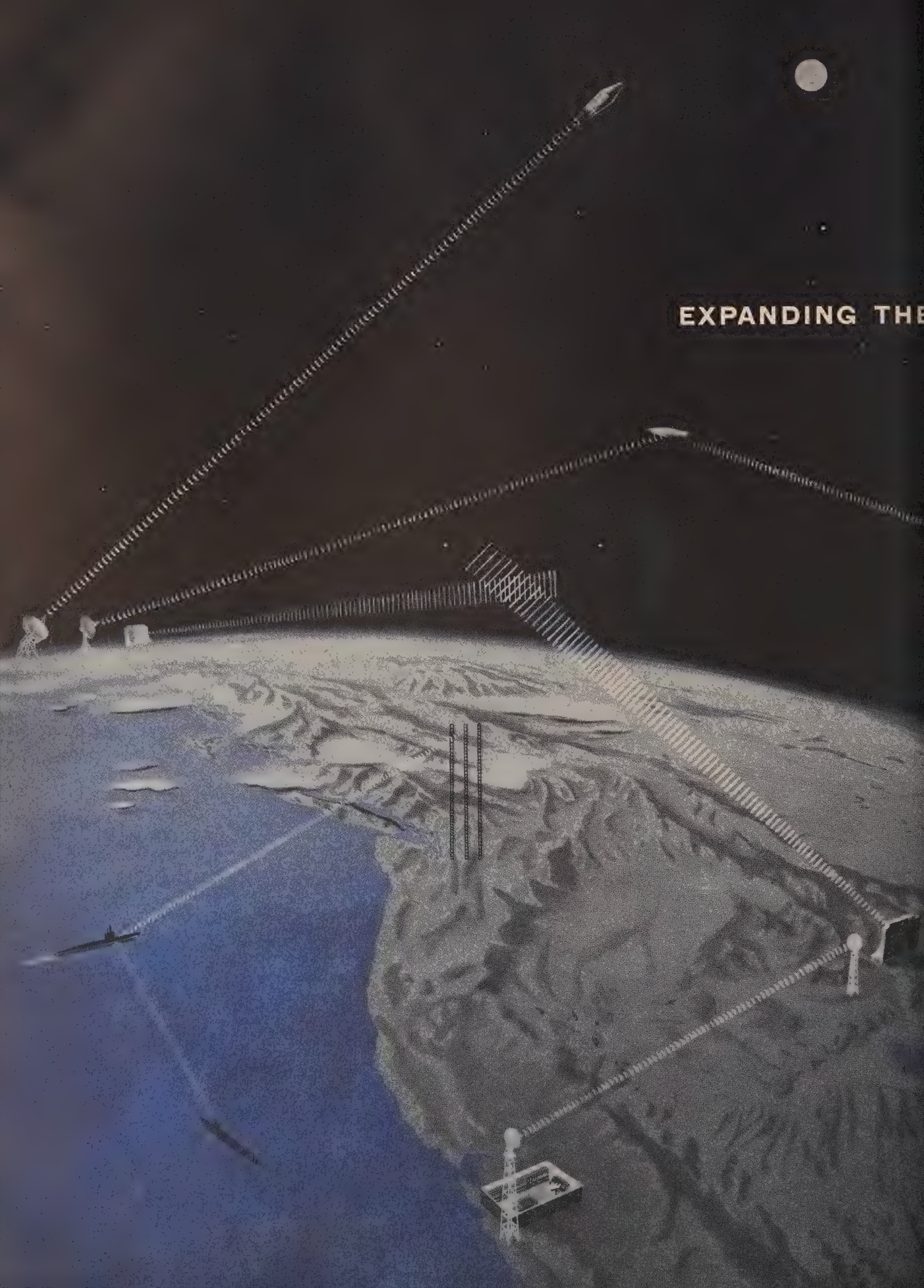
Work in a compact and growing laboratory which offers the creative engineer the opportunity to grow with an expanding organization. Take advantage of the individual recognition and advancement opportunities of a small organization (approximately 200 employees) with the security, benefits and diversified opportunities of a large corporation. Enjoy the ideal northern California climate in relaxed suburban communities with good schools and recreational facilities for your family. Live within 40 minutes of cosmopolitan San Francisco. Know the advantages of being close to leading universities (Stanford is five miles north of the laboratory).

Complete information may be obtained by writing, in confidence,
to Mr. R. R. Keeffe at:

Sylvania Reconnaissance Systems Laboratory
P. O. Box 188, Mountain View, California

SYLVANIA ELECTRONIC SYSTEMS
Government Systems Management
for ***GENERAL TELEPHONE & ELECTRONICS***
GENERAL SYSTEM

EXPANDING THE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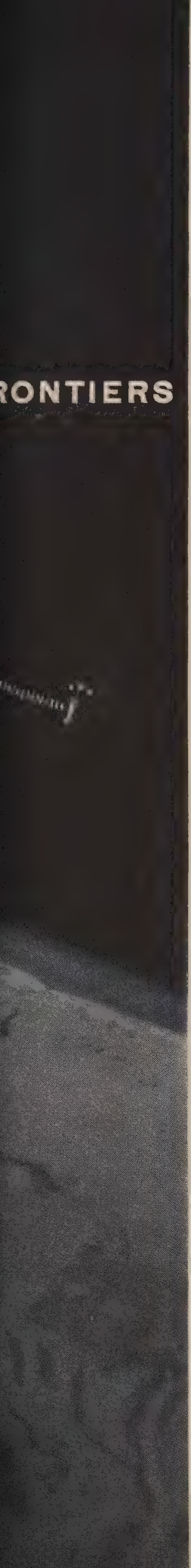

Herodotus, the historian, records (490 B.C.) the use of burnished shields for military signaling. This was the forerunner of the heliograph, invented by Sir Henry C. Mance, which came into wide use centuries later.

RONTIERS OF SPACE TECHNOLOGY IN

COMMUNICATIONS

Lockheed's interest in developing the science of communications extends from the depths of the oceans to deep space. Its Missiles and Space Division research programs deal with the development and application of statistical communication and decision theory in such areas as countermeasures; telemetry multiplexing and modulation; scatter communications; multiple vehicle tracking; millimeter wave generation and utilization; sonic signal detection and processing; avoidance of multipath degradation; and interference avoidance.

Associated research and development efforts are directed toward propagation studies and advanced antenna design; low noise amplifiers; vehicle borne signal transmission and reception, data storage and processing; solid state materials and devices.

The scope of such activities extends from advanced studies of naval communication problems on and under the oceans; the many applications to satellite vehicles; on to the specialized communication problems of deep space explorations. Latter needs are exemplified by high frequencies, low weight and power, high stability, low effective bandwidth, extreme reliability and basic simplicity requirements.

Engineers and Scientists: Investigating the entire spectrum of communications is typical of Lockheed Missiles and Space Division's broad diversification. The Division possesses complete capability in more than 40 areas of science and technology — from concept to operation. Its programs provide a fascinating challenge to creative engineers and scientists. They include: celestial mechanics; communications; computer research and development; electromagnetic wave propagation and radiation; electronics; the flight sciences; human engineering; magnetohydrodynamics; man in space; materials and processes; applied mathematics; oceanography; operations research and analysis; ionic, nuclear and plasma propulsion and exotic fuels; sonics; space medicine; space navigation; and space physics.

If you are experienced in work related to any of the above areas, you are invited to inquire into the interesting programs being conducted and planned at Lockheed. Write: Research and Development Staff, Dept. F-33, 962 W. El Camino Real, Sunnyvale, Calif. U.S. citizenship or existing Department of Defense industrial security clearance required.

Lockheed / MISSILES AND SPACE DIVISION

Systems Manager for the Navy POLARIS FBM;
the Air Force AGENA Satellite in the DISCOVERER,
MIDAS and SAMOS Programs; Air Force X-7; and Army KINGFISHER

SUNNYVALE, PALO ALTO, VAN NUYS, SANTA CRUZ, SANTA MARIA, CALIFORNIA
CAPE CANAVERAL, FLORIDA • ALAMOGORDO, NEW MEXICO • HAWAII

electrical or mechanical engineers

INTERESTING DIVERSIFIED HIGH-LEVEL POSITIONS

Honeywell introduced the first successful autopilot of World War II—the C-1. Since then we have produced more flight control systems than any other company. Today we are engaged in producing the automatic flight control system and the rate stabilization control system for Project Mercury, the flight reference system for the Titan, the solid state autopilot for the F-104, and the adaptive autopilot which controls flight through aerodynamic surfaces and reaction nozzles for the X-15.

One result of our X-15 Adaptive Autopilot effort has been the creation of a permanent reaction control system and development section which has been assigned to our Components Design Department.

Because of our expansion in this area we now have openings for engineers with the following background and experience.

REACTION CONTROL SYSTEMS ENGINEERS

Requires background in missile propulsion systems analysis as it relates to reaction controls. Must be able to establish reaction control requirements by analysis of vehicle dynamics and have an understanding of propellant fuels and oxidizers for specific systems; handle heat transfer problems to optimize and compare several concepts for a given duty cycle; determine optimum over-all performance characteristics, thrust response with given inputs, and chamber pressure and oxidizer-fuel ratios for various nozzle heat sink designs; assist on all proposal efforts requiring propulsion system analysis.

REACTION CONTROL DEVELOPMENT ENGINEERS

Requires background in rocket engine design, specifically bipropellant type. Must be capable in valving design techniques for injection mixing, oxidizer to fuel ratio adjustment, positive shut-off and valve actuation methods, determining thrust at sea level and vacuum with various fuels and combustion chamber designs. Must have working knowledge of high temperature materials and materials compatible with exotic fuels and oxidizers; ability to determine the optimum configuration (nozzle, valves, torque motor, injectors, etc.) for given applications; ability to work with design and layout draftsmen, model makers, and evaluation engineers in following through with a design development.

If you are a qualified engineer, we would like to hear from you. Just drop a line including pertinent information on your background, interests, and accomplishments to Mr. James A. Burg, Dept. 662F, Honeywell Aeronautical Division, 1433 Stinson Blvd. N.E., Minneapolis 13, Minn.

Honeywell

H HONEYWELL *Military Products Group*

To explore professional opportunities in other Honeywell operations coast to coast, send your application in confidence to H. K. Eckstrom, Minneapolis 8, Minnesota.

Positions Open

(Continued from page 124A)

TEACHER IN ELECTRICAL ENGINEERING

Teacher in E.E. beginning Sept. 1960. One qualified and interested in teaching fundamental undergraduate courses plus one graduate course. Ph.D. or MS. required with salary and rank dependent on qualifications. City location with many industrial contacts. Apply Dept. of E.E., Saint Louis University, St. Louis 8, Missouri.

STAFF ENGINEER

Research engineering position for creative person to form nucleus of a new section in the Electro-physical Labs. Will propose and evaluate new electronic component, circuit and systems concepts. Minimum experience and educational background would be 5 years with at least an MS. in E.E. or Physics. A Ph.D. degree would be preferred with strong interests in electronics, theoretical physics or mathematics. Forward resumes to Mr. R. D. Williams, Employment Mgr., P. R. Mallory & Co. Inc. 3029 E. Washington St., Indianapolis, Ind.

TEACHING POSITIONS

The E.E. Dept. of The City College of New York has several positions available on the teaching staff beginning September 1960. Rank and salary commensurate with qualifications and experience. Opportunity for graduate study. Applicants must be present resident of the U.S. Address inquiry to Prof. H. Taub. Dept. of E.E., The City College, Convent Ave., & 139th St., New York 31, N.Y.

ENGINEERS

The University of Denver's Research Institute is seeking graduate electronic engineers in the areas of circuit design and development, system design, and field engineering. Openings exist at all levels from engineers with advanced degrees and several years experience to recent graduates. Opportunities are available for advanced study or part-time teaching in the College of Engineering. Address inquiries to C. A. Hedberg, Head, Electronics Div., Denver Research Institute, University of Denver, Denver 10, Colo.

ELECTRONICS PATENT ATTORNEY OR AGENT

Eastern U.S. company engaged in a broad line of developments in the electronics field has an opening for a patent attorney or agent. Applicant should have excellent comprehension of electronics, together with some experience in patent prosecution. Salary and position will be dependent on background and indicated ability. In reply please supply information as to education, experience and salary expected. Box 2017.

PHYSICIST OR ELECTRICAL ENGINEER

Research on interaction between EM waves and structures or particles. An opportunity to do independent undirected research in the field of plasma or electron physics with excellent technical support and recognized colleagues. An experienced research with original ideas is desired. Salary $10,000 plus, depending on training and experience level. Write Box 2018.

(Continued on page 130A)

active programs in 19 critical electronic areas

Offer You Opportunities
To Participate In Significant
Advances at
STROMBERG-CARLSON
Division of General Dynamics

Top-calibre research and development teams at Stromberg-Carlson are tackling the prime problem areas in electronics affecting commercial communities and national defense. Programs and R & D staffs are expanding, backed by the vast resources of General Dynamics and the Stromberg-Carlson engineer-oriented management.

Every senior engineer and scientist who feels he can contribute to the expansion of man's capabilities in any of the following areas is invited to contact us.

We are particularly interested in people with advanced degrees in Physics, Electrical Engineering or Mathematics and experience in one or more of the areas listed. Please send resume in confidence to Technical Personnel Department.

ENGINEERING AND ADVANCED DEVELOPMENT

Advanced ICBM Communications
Electronic Switching
Nuclear Instrumentation
High-Speed Digital Data Communications
Electronic Reconnaissance Systems
Single Sideband Communications
Synchronous Data Transmission
Advanced ASW Techniques
Machine Tool Automation
Radio Data Links • Tacan Equipment
High Intensity Sound Generators
Advanced Air Acoustics
Shaped Beam Display Systems
High-Speed Automatic Missile Check-Out Equipment
Super-Speed Read-Out and Printing Equipment

RESEARCH

Paramagnetic Resonance • Ferroelectricity
Thin Photoconductor Films
Propagation and Coding • Speech Analysis
Bandwidth Compression • Hydro-Acoustic Transducers
Defect Solid State Physics
Parametric Devices • Molecular Electronics
Tunnel Diode Logic • Scatter Propagation Analysis

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a Division of Ford Motor Company
Newport Beach, Southern California
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SCIENTISTS
MATHEMATICIANS
ENGINEERS

for challenging positions in

RANGE DEVELOPMENT

Junior, senior, staff and management positions.

SYSTEMS ENGINEERING

DATA ACQUISITION
Tracking, Telemetry, Recovery

DATA PROCESSING
Interface Equipment, Data Analysis, Displays

DATA TRANSMISSION
Wire and Radio, Telephone

Range Systems Operations at Aeronutronic, through the immediate expansion of new and existing Range Development programs, has created a number of outstanding opportunities in the following areas:

Missile systems analysis	**Test equipment development**
Missile electronics	**Field test operations**
Downrange instrumentation	**Conceptual design of improved systems**

Positions are at Aeronutronic's new $22 million Engineering and Research Center in Newport Beach, Southern California—the West's most ideal location for living, working and year round recreation. Ford Motor Company employee benefits, considered the finest in the industry, are included.

Interested persons are invited to send resume or inquiries to Mr. L. L. Huling, Range Systems Operations, Aeronutronic, Dept. NR, Ford Road, Newport Beach, California.

RANGE SYSTEMS OPERATIONS | AERONUTRONIC
a Division of FORD MOTOR COMPANY

NEWPORT BEACH, SANTA ANA AND MAYWOOD, CALIFORNIA
NATICK, MASSACHUSETTS

Positions Open

(Continued from page 128A)

ANALOG COMPUTER ENGINEER

The Standard Oil Co. (Ohio) has an immediate opening for an Analog Computer Engineer. A minimum of a B.S. in E.E. or Physics and 2-5 years analog experience is required. Applications are in the field of simulation and study of chemical and refining processes and process control systems. Salary commensurate with experience. Apply Mr. C. A. Bruggers, The Standard Oil Co. (Ohio), 1737 Midland Bldg., Cleveland, Ohio.

MEDICAL ENGINEERING

Electronics Engineer or Physicist. Permanent position in Dept. of Surgical Research of a large eastern university, involves design of new instruments, supervision of maintenance of equipment, and consulting with physicians. Salary range open. Send complete resume to Box 2019.

ENGINEER

Engineer to conduct a research and development program on instrumentation for data accumulation, reduction, and processing in geology, water resources investigations, photogrammetry, and allied fields including the development of new equipment and techniques for sensing, digitizing, logging, transmitting, storing, and processing of mass data. Contact Personnel Officer, U.S. GEOLOGICAL SURVEY, Washington 25, D.C.

ELECTRONIC ENGINEER

Electronic Engineer to teach lecture and laboratory courses. Up-to-date knowledge of the field required. Working and living conditions excellent; salary and opportunity very attractive. Write to Dean of Engineering, California State Polytechnic College, San Luis Obispo, Calif.

ELECTRICAL ENGINEERING

Excellent opportunities for qualified Ph.D.'s in logical design, network synthesis and other areas. Rank and salary commensurate with research and teaching qualifications. Teaching loads at all ranks are low. They are reduced further for those handling sponsored research projects. Each faculty member is expected to develop and maintain a strong research program. Send complete resume including research publications to Chairman, Dept. of E.E., Northwestern University, Evanston, Ill.

ELECTRICAL ENGINEERS

Electrical Engineering staff openings. Both graduate and undergraduate courses. M.S. required, Ph.D. desirable. Modern facilities. Active research program. Write: Joseph C. Michalowicz, Head, E.E. Dept., Catholic University, Washington 17, D.C.

ELECTRONIC ENGINEERS—TECHNICIANS

The Federal Aviation Agency needs qualified Electronic Engineers and Technicians in Alaska for installation and maintenance of electronic equipment and systems for air navigation, air traffic control, telecommunications, etc. Career Federal Civil Service qualification requirements and benefits. Moving costs paid. Annual compensation $6700 and up depending upon qualifications. Contact FAA, P.O. Box 440, Anchorage, Alaska.

(Continued on page 134A)

RELIABILITY — If a complex electronic equipment or system is not available for complete and immediate satisfactory operation, it is worthless to its user. The imperative need for greatly increased product reliability has spawned a new engineering art . . . Reliability Engineering.

Federal Electric pioneered much of the present day techniques in Reliability, and is engaged in one of the most extensive equipment and systems evaluation programs in industry. With an organization spread over most of the globe, serving under every conceivable operational condition, Federal Electric maintains a world-wide field data feedback system which provides comprehensive component, circuit and system failure data.

Already several years ahead of the industry, our Reliability Engineers today are actively aiding development and production engineers in their efforts to provide electronic products of greater sophistication and greater reliability. Hand in hand with these efforts are maintainability programs from which will result comprehensive design criteria for application, early in the design phase, of sound engineering principles to the problem of equipment maintenance.

The Equipment and Systems Evaluation Department of FEC's Central Engineering Division, at our Paramus home offices, is staffed with engineers whose collective skills and experience represent the state-of-the-art in Reliability. They are aided in their evaluation engineering by modern computer and communications equipment including the high-speed, accurate field failure reporting network.

Engineers with a degree in E.E. and experience in design and development or circuit analysis or field engineering are invited to inquire about outstanding positions in this group. Write Mr. H. R. Gudenberg, Dept. XX.

FEDERAL ELECTRIC CORPORATION
Service Division of International Telephone and Telegraph Corporation
Paramus Industrial Park, Paramus, New Jersey

ITT

How to take a longer look

The development of advanced electron tubes is just one of the many projects now under way at the Hughes Research Laboratories in Malibu, California.

at air space

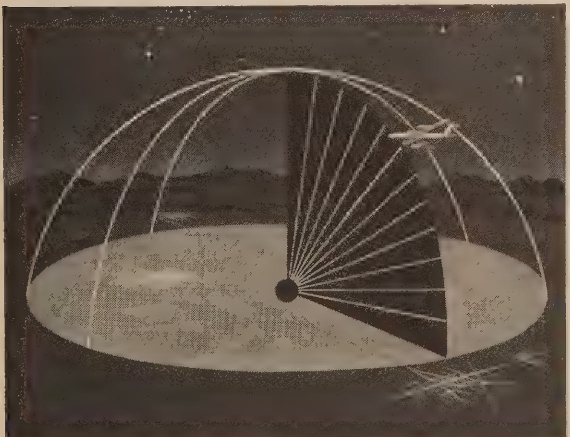
The problem presented to Hughes engineers: Build an airborne navigation, target acquisition, armament control system of far greater dimension than ever before.

Hughes engineers solved this challenging problem with several important state-of-the-art advances. One of the most significant was the development of a unique and highly advanced Traveling Wave Tube. This tube's two outstanding advantages: 1) higher power to provide greater range; 2) broader frequency band width for greater operational flexibility.

In addition, Hughes engineers designed a radar system that will discriminate against ground return and will detect targets at extreme ranges. Designed to operate in a "hard" counter-measures environment, the radar system was augmented with infrared detection and tracking.

This, and many other Hughes activities in virtually every area of advanced electronics provide the far-seeing engineer with a wide choice of interesting assignments.

A few representative project areas include: advanced data processing systems, molecular electronics, hydrofoil systems, anti-submarine warfare systems, advanced 3-D surface radar systems, space vehicles, nuclear electronics, miniaturized communication systems, ballistic missiles, infrared devices—and a great many others.



FRESCANAR is a Hughes development that gives umbrella-like radar protection. It positions radar beams by electronic rather than mechanical means.

The commercial activities of Hughes have many interesting assignments open for imaginative engineers to perform research, development, manufacturing of semiconductors, storage tubes, microwave components, radiation devices, and microwave tubes.

Whatever your field of interest, you'll find Hughes' diversity of advanced projects gives you widest possible latitude for professional and personal growth.

Newly instituted programs at Hughes have created immediate openings for engineers experienced in the following areas:

- Electroluminescence
- Infrared
- Solid State Physics
- Digital Computers
- Reliability & Quality Assurance
- Systems Design & Analysis
- RF Network Engineering
- Microwave & Storage Tubes
- Communications Systems
- Inertial Guidance
- Field Engineering
- Circuit Design & Evaluation

Write in confidence to Mr. R. A. Martin
Hughes General Offices, Bldg. 6-E6, Culver City, Calif.

Creating a new world with ELECTRONICS

HUGHES

HUGHES AIRCRAFT COMPANY
Culver City, El Segundo, Fullerton, Newport
Beach, Malibu, Oceanside, Santa Barbara and
Los Angeles, California; Tucson, Arizona

LINCOLN LABORATORY

invites inquiries from persons with superior qualifications.

SOLID STATE Physics, Chemistry, and Metallurgy

RADIO PHYSICS and ASTRONOMY

NEW RADAR TECHNIQUES

COMMUNICATIONS:

- **Techniques**
- **Psychology**
- **Theory**

INFORMATION PROCESSING

SYSTEMS:

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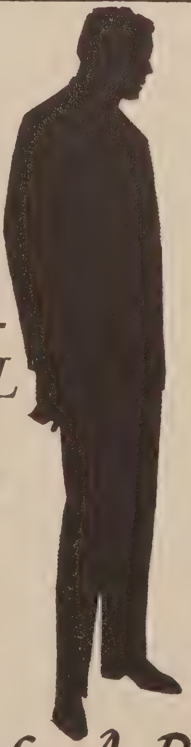
- **ICBM Detection and Tracking**
- **Strategic Communications**
- **Integrated Data Networks**

SYSTEM ANALYSIS

Research and Development
LINCOLN LABORATORY
Massachusetts Institute of Technology
BOX 16 • LEXINGTON 73, MASSACHUSETTS



THE *EXCEPTIONAL* MAN

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when you need a man who is well educated and trained in the specialized fields of knowledge you require . . .

you need The Exceptional Man.

Let us locate him for you.

Charles A. Binswanger INCORPORATED **ASSOCIATES**
EXECUTIVE SEARCH SPECIALISTS
407 AMERICAN BUILDING • BALTIMORE 2, MD. • PLAZA 2-5013

Positions Open

(Continued from page 130A)

ENGINEERS—PHYSICISTS

Company engaged in research, production and development of camera tubes, infrared devices and image amplifiers seeks graduate engineers and physicists to work in new laboratories at beautiful Fort Washington, Pa. Reply to Box 2020.

PROFESSOR

Rapidly expanding engineering school located in snow-free, smog-free area with ideal climate needs electronic engineer to teach undergraduate courses and to help develop graduate program. MS. minimum requirement. Salary dependent upon industrial experience and graduate degree. Modern facilities and equipment with new building under construction. Apply to Prof. M. P. Capp, Engineering Div., San Diego State College, San Diego 15, Calif.

TEACHING—RESEARCH

Positions at all ranks for well qualified persons with MS. or Ph.D. in developing department in an engineering school with a new program which emphasizes engineering sciences and interdepartmental teaching. Research presently in areas of signal detection and propagation with others being developed. 9 month or full year appointments available. Salary to $13,500 on full year basis. Write to A. T. Murphy, School of Engineering, University of Wichita, Wichita, Kansas.

TECHNICAL MANAGER

Advanced Data Processing Systems. Direct planning requirements for organization of comprehensive business information processing systems. Requires a Ph.D. in E. E., physics or math., plus several years experience in digital data processing systems. Managerial experience desirable. Attractive salary. Forward resume to Box 2021.

ASSISTANT PROFESSOR

Assistant Professor of Electrical Engineering. Ph.D. required with interest in circuit theory, physical electronics or solid state. Active research and graduate program. Contact W. P. Smith, Chairman, E. E. Dept., University of Kansas, Lawrence, Kansas.

ELECTRONIC TECHNICIANS

Electronic technicians available—June graduates of Sewanhaka High School, Floral Park, Long Island want full, part time jobs. Have had 3 years training in electronic and electrical shop and theory. Please contact Mr. Henry Aungst, Placement Director, Sewanhaka High School, 500 Tulip Ave., Floral Park, Long Island. Tel. Floral Park 4-1500.

ELECTRICAL OR ELECTRONICS ENGINEER

Large medical institution is interested in employing an engineer to direct the maintenance and trouble-shooting of a large variety of complex electrical instrumentation, and to make modifications in existing equipment. Position requires a person with a degree in E.E. and a minimum of 4 years experience in one or more of the following fields: electrical instrumentation; field engineering or electrical instruments; computers, f.m. tape equipment; telemetering equipment; radiation equipment and counters. Write Personnel Section, Mayo Clinic, Rochester, Minnesota.

CALIFORNIA

AGAIN THE LAND OF PROMISE

Science has brought us to a unique vantage point from which we can foresee vast technological change. As the curve of scientific progress approaches the vertical, today's pioneers who wish to contribute significantly in their chosen fields will do well to consider the unequalled challenge offered by association with one of the nation's foremost scientific laboratories. Positions are currently available in physics, electronics, mathematics, and in mechanical and aeronautical engineering, as well as in other technical disciplines.*

The diverse locations of the Naval Laboratories . . . the varieties of climate and recreation . . . assure your discovery of life as you want it. Address your inquiry to:

U. S. NAVAL LABORATORIES

in California
Personnel Coordinator, Dept. A
1030 East Green Street
Pasadena, California

- **The Pacific Missile Range and U. S. Naval Missile Center, Point Mugu:** National launching and instrumentation complex, guided missile test and evaluation, astronautics, satellite and space vehicle research and development.
- **U. S. Naval Ordnance Test Station at China Lake and Pasadena:** Developers of guided missiles, rockets, advanced propulsion systems, torpedoes, and other undersea weapons.
- **U. S. Naval Ordnance Laboratory at Corona:** Developers of guidance and telemetry systems and other missile system components. Researchers in such fields as IR spectroscopy, magnetism and semiconductors.
- **U. S. Naval Radiological Defense Laboratory at San Francisco:** The nation's only major center for research on nuclear effects and development of counter measures.
- **U. S. Navy Electronics Laboratory at San Diego:** One of the Navy's largest organizations engaged in the research and development of radar, sonar, radio and acoustics.

*These positions are in the Career Civil Service.

analytical, systems, components engineers

CHECK THESE OPENINGS IN FLIGHT CONTROLS WITH HONEYWELL AERONAUTICAL

Honeywell introduced the first successful electronic autopilot in 1941—the C-1 of World War II. Since, we have produced more flight control systems than any other company and have developed concepts in flight controls that are now standard in this field. Today, most top aircraft and missiles are equipped with Honeywell flight controls. Honeywell's Flight Control Systems Group has expanded steadily and now has openings for the following:

ANALYTICAL ENGINEERS—must be capable of simulating (mathematically on paper or computers) characteristics and problems in missiles and aircraft control, stability, and control systems. Should have good math backgrounds with analog computer experience.

SYSTEMS ENGINEERS—should be capable of interpreting analytical results into navigation, guidance, or flight control systems. Should be electrical engineers experienced in systems—ideally, with experience in flight control in the aviation industry.

COMPONENTS ENGINEERS—should be electronics men with emphasis on transistor circuitry. Will be responsible for designing components which go into the system. Must have circuitry design experience.

To discuss these or other openings, write Mr. James A. Burg, Dept. 662B, Aeronautical Division, 1433 Stinson Blvd., Minneapolis 13, Minn.

Honeywell

H Military Products Group

To explore professional opportunities in other Honeywell operations coast to coast, send your application in confidence to H. K. Eckstrom, Minneapolis 8, Minnesota.

Positions Wanted

By Armed Forces Veterans

In order to give a reasonably equal opportunity to all applicants and to avoid overcrowding of the corresponding column, the following rules have been adopted:

The IRE publishes free of charge notices of positions wanted by IRE members who are now in the Service or have received an honorable discharge. Such notices should not have more than five lines. They may be inserted only after a lapse of one month or more following a previous insertion and the maximum number of insertions is three per year. The IRE necessarily reserves the right to decline any announcement without assignment of reason.

Address replies to box number indicated, c/o IRE, 1 East 79th St., New York 21, N.Y.

MARKETING DIRECTOR-SALES MANAGER

Desires to relocate. Connecticut preferred. Excellent background in building and managing electronic sales organizations. Experienced in directing all phases of marketing activities. Age 37, married. Resume furnished on request. Box 2061 W.

UNIVERSITY ADMINISTRATOR

11 years college administration and teaching experience, plus industrial research, electronic design and development. Currently conducting year's research in industry. Have directed grant programs, technical adult education, research, taught undergraduate and graduate. BS. and MS. in E.E. Married. Age 36. Excellent references. Interested in challenging college position. Prefer Rocky Mountain area. Box 2062 W.

ELECTRICAL ENGINEER

BSEE. 1957. 1/Lt. Sig. C. 1½ years as Project Officer at WSMR, New Mexico. Experience in the field of guidance and countermeasures of missiles. Interested in obtaining a LL.B. Desires position which requires an engineering and legal combination with management opportunities. Box 2072 W.

ELECTRONICS ENGINEER

European assignment desired in western or southern Europe in management, technical or liaison area. 15 years experience R and D, both civilian and military, in communications, electronic countermeasures, television and missile electronics. Considerable supervisory experience. BEE. and MEE. degrees. Box 2073 W.

ELECTRONICS ENGINEER

BS. in Physics. MSEE. 5 years experience in transistorized digital computer circuit design and radar-computer systems. Single, age 28. Desires position in western Europe. Box 2074 W.

ENGINEERING MANAGER

Communications systems engineering of telephone, radio relay, microwave, HF and SSB Systems. 20 years military experience all phases applied engineering, siting, installation, operation and maintenance. Performed Staff Engineering assignments at Pentagon and major command levels. Currently Deputy Chief, Maintenance Engineering & Test Branch, multi-billion dollar air defense project office. Supervisory experience with over 500 personnel. 21 months military electronics schooling plus BBA. and MBA. and 14 months training with industry. Senior Member IRE. Desires managerial position with growth potential. Available August 1960. Box 2075 W.

ENGINEER

BS. graduate with electronics major desires position in component or systems design engineering. Have pilot license. Prefer Minnesota or midwest area. Box 2076 W.

SENIOR CONSULTING ENGINEER

Associate Professor of Nuclear Engineering desires summer employment leading to a consulting position; BSEE. 1949, MSEE. 1951; 7 years industrial and 3 years teaching experience in electronic and nucleonic instrumentation, microwaves and radioisotope techniques; active security clearance, AEC licenses, located in southwest. Box 2077 W.

ENGINEERING MANAGER

MSEE. degree. Background includes all levels in R and D to 3 years as manager of development groups. 12 years experience in analog and digital instrumentation, data processing, and automation with an even division between missile and industrial fields. Will relocate to either coast. Box 2078 W.

(Continued on page 138A)

CHIEF ENGINEER

This key position in our organization requires a man with excellent administrative and design capabilities to direct product development and engineering of a rapidly-growing line of high quality electronic instruments. Location in the pleasant

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New technical tests enable you to calculate your probability for success at LMED – in 1 hour at your own home!

BY GENERAL ELECTRIC'S LIGHT MILITARY ELECTRONICS DEPARTMENT

If you've been thinking of changing your job some day—or in the near future—but have hesitated because of the many uncertainties involved, Light Military's new concept in professional job selection will be of paramount interest to you.

What is it?

The new concept is based on a series of technical tests developed and pretested by Light Military engineers. They are designed to be taken, scored and evaluated by the individual engineer, all in the privacy of his own home. And, because the sole purpose is to provide you with a novel, objective means for self-appraisal, your score need not be divulged to us at any time.

Here's how it works:

First, fill out the coupon below and check off the tests which apply to your training and professional experience. Forward the completed coupon to us and in a few days you will receive the tests, a sealed answer sheet and explanatory material.

During a convenient hour at home, take the test and score it with the answer sheet provided. Then, compare your performance with the criterion group composed of Light Military engineers at all levels who took the same test. In most cases you will be able to relate your score to years of experience, from 2 to more than 10.

What it measures:

If your adjusted score is equal to, or more than the years of experience you possess, the probability is excellent that a significant community of technical interest exists between you and The Light Military Department. In addition, a valid assumption can be made that a high probability for success awaits you here. And remember, your score need not be divulged to us at any time; it is for your own guidance exclusively!

……

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SPACE COMMUNICATIONS & TELEMETRY • MISSILE & SATELLITE COMPUTERS • SPACE VEHICLE GUIDANCE • UNDERSEA WARFARE SYSTEMS • THERMOPLASTIC DATA STORAGE • SPACE DETECTION & SURVEILLANCE • COMMAND GUIDANCE & INSTRUMENTATION • INFRARED MISSILE APPLICATIONS

……

Facts about the tests

1 Each technical test is composed of 40 multiple choice questions.

2 To find answers for some questions, mathematics is involved—but only to the degree normally associated with the work.

3 The "mix" of questions includes some easy ones, some bordering on the state of the art.

4 None of our engineers achieved a perfect score.

5 The test for Engineering Administration is psychological, designed to reveal aptitudes and abilities most often found in good engineering managers or administrators.

MAIL THIS COUPON FOR YOUR TESTS

Mr. R. Bach
Light Military Electronics Dept.
General Electric Company, French Road, Utica, New York

Please send me tests (limited to 2 subjects per individual) answer and self-evaluation sheets covering the areas checked:

☐ RADAR ☐ MICROWAVE ☐ ELECTRONIC PACKAGING (ME)
☐ COMMUNICATIONS ☐ ADMINISTRATIVE ENGINEERING

NAME ______________________________

HOME ADDRESS ____________________ HOME PHONE ____________

CITY ____________________ ZONE ______ STATE ____________

DEGREE(S) ____________________ YEAR(S) RECEIVED ____________

53-MF

LMED

LIGHT MILITARY ELECTRONICS DEPARTMENT

GENERAL ELECTRIC

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Operations Research is a young science, earning recognition rapidly as a significant aid to decision-making. It employs the services of mathematicians, physicists, economists, engineers, political scientists, psychologists, and others working on teams to synthesize all phases of a problem.

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No other Operations Research organization has the broad experience of ORO. Founded in 1948 by Dr. Ellis A. Johnson, pioneer of U. S. Opsearch, ORO's research findings have influenced decision-making on the highest military levels.

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ORO starting salaries are competitive with those of industry and other private research organizations. Promotions are based solely on merit. The "fringe" benefits offered are ahead of those given by many companies.

The cultural and historical features which attract visitors to Washington, D. C. are but a short drive from the pleasant Bethesda suburb in which ORO is located. Attractive homes and apartments are within walking distance and readily available in all price ranges. Schools are excellent.

For further information write:
Professional Appointments

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ORO The Johns Hopkins University
6935 ARLINGTON ROAD
BETHESDA 14, MARYLAND

Positions Wanted

By Armed Forces Veterans

(Continued from page 136A)

ELECTRONICS ENGINEER

Mature, very active, electronics engineer anticipating retirement from technical military duties at 50 interested in challenging Engineering Management position; 7 years complex electric power service problems; 19 years broad Navy engineering management duties in diverse U.S. and overseas communications and antisubmarine electronics systems projects and construction, scheduling work. Trained to relocate periodically on short notice and quickly assume specific responsibility for important technical projects requiring smooth coordination with other staff specialists. Outstanding references and accomplishments. Recent technical refresher training. Particularly interested in Phila. Pa. or Calif. areas, but will consider any long range opportunity. Box 2079 W.

ENGINEER

Supervisory engineer of systems or sales on systems management or evaluation of electromechanical weapons system equipment in radar, computers, etc. and microwave components. Have excellent market and sales background with industrial and government agencies on prime hardware or components. Home base New York City or Long Island. Will travel extensively if necessary. MSEE. Matured. Formerly Lt. Colonel in the USAF. Box 2080 W.

TEACHING

British, age 35; Member IRE, IEE. Telecommunications engineering diploma. 10 years lecturing, 4 years as head of department. Seeks U.S. teaching appointment in E.E. Dept. where facilities exist for working towards MS. degree. Experienced administrator. Visited U.S. 1959. Familiar with E.E. curricula. Specialties; circuitry and measurements. Frustrated by bureaucracy. Box 2081 W.

ENGINEER

Communications equipment, design circuitry and hardware. BSEE., MSEE. Seeks assignment Continental Europe. Top Drawer company only. Age 34; 9 years experience. Box 2082 W.

ELECTRICAL ENGINEER

5 yr. E.E. plus good Liberal Arts background. Polyglot; age 31; family; lifelong U.S. citizen. Diverse experience ranging from power during military, 3½ years design and manufacture electric electronic instrumentation and control, 2 years solid state R and D, 1 year specifications and estimating for contracts and projects, 4½ years supervisory, presently project level problem solver and trouble shooter for large company on communication, navigation, ultrasonic and control. Box 2084 W.

ELECTRONICS ENGINEER

AB., BSEE. Columbia; Tau Beta Pi, Eta Kappa Nu. Some graduate E.E. and physics. LTJG, U.S. Navy; Destroyer electronics and E.C.M. Officer, 9 months; Electronics Instructor, D.A.S.A., 2½ years. Married, family. Desires R and D position in east with management opportunities. Available September 1960. Box 2085 W.

ADMINISTRATIVE ENGINEER

Desires position of responsibility as Technical and Administrative Assistant to Director of Engineering or General Manager in U.S. or overseas. 10 years varied experience in Military and Comm. Elec. Systems. Shared responsibility for 5 million European Plant. Resume sent to management. Box 2091 W.

ELECTRICAL ENGINEER

Four years active duty as Naval Officer. MSEE. University of Illinois 1958. Last 2 years spent in development of high power klystron transmission systems and system controls. Desires position in system management or administration in medium sized concern. Box 2092 W.

ELECTRONIC ENGINEER

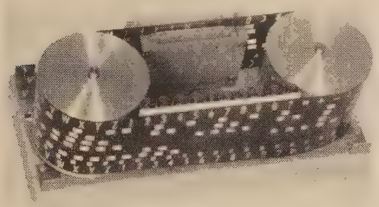
Position desired in commercial product or industrial automation fields. 15 years experience in data processing and display fields. MS. in E.E. Preferred location—Southwest. Box 2093 W.

NEWS New Products

(Continued from page 122A)

Read-Out Device

A versatile new read-out device, RANDID (Rapid Alpha Numeric Digital Indicating Device), has been developed by **Hazeltine Corp.,** Little Neck 62, N. Y.



The characters or symbols to be displayed are photographically reproduced on the belt and appear as transparent characters on an opaque background. Code tracks, which are similarly reproduced on the belt, provide a binary coded identification of each character. By suitably scanning the code tracks with incandescent lamps and phototransistors, a code signal is generated which serves to identify the location of each character on the belt.

Change of characters or character style can be accomplished merely by changing the belt, an operation which takes but a few minutes. Because of its unique design, RANDID can be utilized where a multi-window, multi-line display is required. Some of its applications include: Aircraft Panel Display, Digital Data Transmission Monitor, Card or Tape/reader/verifier, Visual Decoder, Information Retrieval Display, Computer Readout, Small Tote Board, Test Equipment Readout, etc.

The display of a particular character in a particular display window occurs when the generated binary code signal corresponding to the selected character and display position, agrees with the binary code of the input signal. When the two codes agree, a high intensity neon lamp is fired which stroboscopically illuminates

(Continued on page 140A)

ENGINEERS

NOW—CHOOSE YOUR ASSIGNMENT AND LOCATION THROUGH OUR NATION-WIDE PLACEMENT SERVICE

SALARIES $7,500 TO $18,000

We can offer you a large selection of diversified positions with America's foremost electronic organizations. Some positions for non-citizens.

The following are just a few of a large number of desirable opportunities.

SR. ENGR.—DIGITAL COMPUTERS— Exp. required in systems, logical design, packaging, system integration or pulse circuitry. To $15,000

FLIGHT TEST EVALUATION—Sr. Opp in Ground & Flight Test on data links, precision transducers, telemetering equipment, power supplies, circuit monitors and impedance matching units. To $15,000

RF ANTENNA—Proj. Engr. $15,000

INFRA RED—Proj . Engr. $15,000

CIRCUIT DESIGNERS — 2-5 years Transistor experience. $11,000

ADVANCED SYSTEM DEVELOPMENT —Supervisory position in digital computer, fire control or missile guidance development. To $17,000

PHYSICIST Phd.—Nuclear experience pertaining to radiation from propulsion units—unusual opportunity. To $18,000

PROJECT LEADER—Antenna Pedestals. $13,000

SR. ENGINEER—DEVELOP Airborne & spaceborne communications systems. $15,000

Just tell us what you would like to do and where you would like to locate, and we will handle everything for you without cost or obligation.

LOCATION DESIRED

☐ New England
☐ Northern East Coast
☐ Southern East Coast
☐ Midwest
☐ Southwest
☐ West Coast

POSITION DESIRED

☐ Systems
☐ Radar
☐ Transistors
☐ Tubes
☐ TV Receivers
☐ Microwave
☐ Anal. Computers
☐ Dig. Computers
☐ Antenna
☐ Servo-Mechanisms
☐ Navigation
☐ Counter Measures
☐ Telemetering
☐ Nucleonics
☐ Ind'l. Instruments
☐ Components
☐ Circuit Design

WHAT SATISFIED ENGINEERS SAY:

Dear Mr. Brisk:
This is to advise you I have accepted employment with ———— Company as a project leader at $15,000.
Your service has been a real help to me, for I am sure I could not have found this unusual opening by myself.
Thank you.
H.M.P.

Dear Mr. Brisk:
I have today advised ———— Company that I would be pleased to accept their offer. I start August 1st as a senior engineer at $13,000.
The opportunity is one of the most outstanding I have seen.
J.S.E.

A National Electronic Placement Service Established in 1937.
You are assured of prompt and completely confidential service by forwarding three resumes to **HARRY L. BRISK,** ***(Member IRE)***

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Our client companies, a select group chosen for their reputations as enlightened prestige organizations, are located in every part of the country and represent every area of electronics activity—including challenging commercial projects. Salaries in general run from $8,000 to $20,000.

You'll find that Cowin Associates' background in both professional electronic R & D and recruitment will expedite your move to a more responsible and more rewarding position. Relocation assistance, when necessary, is provided by our client companies—who also pay our search fees.

We invite you to forward your resume to Mr. D. M. Cowin.

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MANAGER—Reliability systems

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PROJECT ENGINEERS—Gyros, synchros, amplifiers, radar, systems

CHIEF PROCESS ENGINEER—Germanium diodes

CIRCUIT DESIGN ENGINEER—Cathode ray

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ELECTRONICS AND PHYSICS

Southern Research Institute has openings for senior electronic engineers or engineering physicists in the field of instrument development. Current activities on an expanding series of projects can be summarized by the title Photoelectronics. Successful progress on the work calls for advancing frontiers in electronic circuits, physical and geometrical optics, and kinematic design of instrument components.

An applicant should preferably have an M.S. or Ph.D. degree in electrical engineering or engineering physics, or equivalent experience, and should have a keen desire to become a leader in this field.

If you are looking for an opportunity to work in this interesting and challenging field, please write, giving a summary of your education and experience to

SOUTHERN RESEARCH INSTITUTE
Birmingham 5, Alabama

(Continued from page 139A)

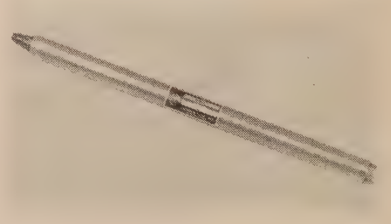
the selected character. The belt speed, and thus the stroboscopic repetition rate of each character, is such as to present a flickerless display. Typical repetition rates vary from 30 to 60 strobes per second with motor speeds of from 1800 to 3600 RPM. Rotational speed changes cause only a change in the repetition rate and do not otherwise affect the display of information.

Transistorized circuits affording electronic storage facilities, code comparison and strobe drivers are contained in a unit which can be located remotely from the display unit. The electronic storage facilities enable RANDID to accept input information in either dc or pulse binary-coded decimal form and permit nondestructive readout of the displayed information.

The flexibility of RANDID affords variation of input codes (i.e. 4–6 bit etc.), character size and/or style, number of characters per line, number of lines per display. A distinctive feature of RANDID, desired in many applications, is selective address and erasure. Since RANDID may be produced in various sizes and forms, prices and delivery dates on this new development are dependent upon customer specifications and applications.

Electrostatically Focused TWT

Typical of the line of electrostatically focused, L-Band Amplifier Traveling Wave Tubes being manufactured by **Huggins Laboratories,** 99 E. Arques Ave., Sunnyvale, Calif., is the HA 27. This tube operates on a frequency range of 1.0 to 2.0 kmc with a small signal gain of 30 db minimum and a saturation power output of 7 dbm minimum. Savings in weight and size have been effected in the HA 27 which measures 1″ in diameter and 16″ in length. Net weight is 1.0 lb. The HA 27 meets the requirements of military specifications in operating temperatures, vibration and shock performance.



No magnetic structure either solenoid or permanent magnet is needed by the HA 27. Complete characteristics and prices may be secured by writing to Huggins.

Microminiature Rivets

A new fastener for subminiature electronic and instrument needs has been announced by the **Circon Component Corp.,** Santa Barbara Municipal Airport, Goleta, Calif.

(Continued on page 142A)

T/I

needs an S-C product engineer
whose design philosophy
is reliability

to develop and improve diodes,
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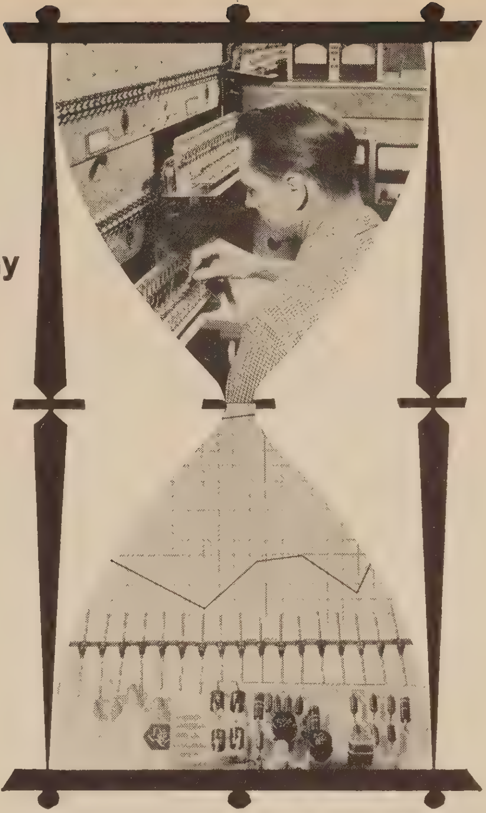
capacitors, resistors



succeed
in '60
with
T/I

At TI's Semiconductor-Components division, product engineers of integrity have the opportunity of putting their talents to work in an atmosphere where reliability is the only acceptable design philosophy. Here the daily challenge is to make the world's best semiconductor products at the lowest possible cost without sacrificing dependability. ■ As a TI S-C product engineer it would be your responsibility to strive constantly to adopt new techniques and technologies toward improvement, simplification and increased reliability of existing processes and products. ■ We now require product engineers to undertake challenging key assignments in reliable design, development and evaluation of ultra-fast computer diodes, tunnel diodes, rectifiers, controlled rectifiers, voltage regulators, resistors, and tantalum and other advanced types of capacitors. ■ You qualify as a product engineer for semiconductor component projects if you have a degree in Electrical Engineering, Physics or Physical Chemistry and at least three years experience in diode, capacitor or resistor design and circuitry.

OTHER PROFESSIONAL POSTS AVAILABLE:

- Component Packaging Engineers
- Circuit Development Engineers
- Test Equipment Engineers
- Electronic Sub-Systems Engineers (Standard and Modular)

INTERVIEWS in your area will be held in the near future. If you qualify for positions described, please send resume immediately to C. A. BESIO, DEPT. 115.

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DISPLAY DEVICES
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Chicago, Ill., and Menlo Park, Calif.

The continuing expansion program at Zenith has created new opportunities for engineers with experience in the above fields.

The fast-wave **electron-beam parametric amplifier,** conceived at Zenith, has opened up challenging new fields for research and development activity from UHF to SHF bands. Broad company interests in the microwave-tube area provide fertile atmosphere for original ideas and individual initiative.

An expanding research program in new fields centered around **compound semiconductors** provides opportunities for individuals with backgrounds in the solid-state art. Development of special devices for highly specific purposes, in collaboration with applications engineers, represents another area of active interest in the semiconductor field.

Positions are now available in the Research Department at Chicago; some openings are available in the San Francisco Bay Area. Congenial small-group atmosphere prevails, with all the advantages of a large, progressive company.

Interested applicants please contact:

DR. ALEXANDER ELLETT
Zenith Radio Corporation
6001 Dickens Avenue
Chicago 39, Illinois

BErkshire 7-7500

RESEARCH AND DEVELOPMENT DEPARTMENT
OF CONTINENTAL OIL COMPANY,
PONCA CITY, OKLAHOMA

has immediate opening—EE or Physics. Advanced Degree or equivalent with experience in design and fabrication of electronic instruments. Salary commensurate with experience. Send detailed résumé to

INDUSTRIAL RELATIONS DEPARTMENT
CONTINENTAL OIL COMPANY
PONCA CITY, OKLAHOMA

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 140A)

The rivet type fastener embodies an entire line in sizes smaller than the smallest rivets heretofore commercially available. It will make immediately available from stock specialized rivets which previously have had to be fabricated by the user. Many sizes in the line are smaller than can be produced on conventional rivet making machinery.

The head form is a modified brazier with low contour and minimum functional diameter for the stresses imposed.

Mechanical design of the new rivet has been directed specifically toward instrumentation and electronic use. It combines advantages of both solid and tubular rivet styles in a concentrically deep drilled shank. This provides the ease of setting so essential in small or delicate assemblies. The solid upper portion of the rivet contributes rigidity and prevents buckling or bending in the upsetting or clinching operation. The drilled section controls material flow and accomplishes an effective clinch with a minimum of pressure on the parts or material being assembled.

Material is specification non-magnetic brass with the alloy controlled to insure setting ease and uniformity of the swaged or upset clinch.

The instrument finish which is 24 carat gold electropolated and shot burnished will be standard on the new microminiature rivet line. This finish is impervious to rigorous environments, provides a good electrical contact and retains its soldering characteristics indefinitely.

Quality Assurance For Printed Circuits System

A complete quality assurance system for the manufacture of printed circuits is described in an illustrated technical bulletin just published by **Photocircuits Corp.,** one of the leading manufacturers of printed circuits and precision devices employing printed circuits

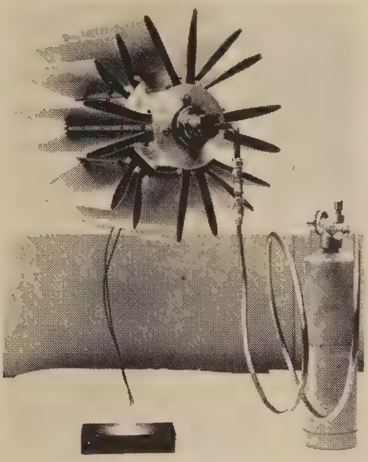
The two color bulletin covers in detail quality control procedures in accordance with military specifications MIL-Q-9858 and MIL-STD-105.

Functions of the quality assurance system outlined in the bulletin include interpretation of customer specifications; transformation of specifications into quality assurance criteria and procedures; use of statistical techniques, control charts and methods to maintain consistent quality; maintaining records, process averages and issuing reports; performance of studies on capabilities of all processes, machines and tools; conducting special studies and experiments; and selection of suppliers and determining vendor quality conformance.

Copies of the New technical bulletin Number P-10, "Quality Assurance for Printed Wiring," are now available on request from Department 1700, Photocircuits Corp., 31 Sea Cliff Ave., Glen Cove, New York.

Thermoelectric Generator

General Instrument Corp., Thermoelectric Div., Newark, N. J. (March 22, 1960) placed on the market a small (one-foot high), lightweight (10 pounds) automatic "power plant," with no moving parts, that can produce electricity for a year on $10 worth of ordinary propane gas and will keep running as long as the fuel supply lasts.



Believed by the Company to be "the first practical thermoelectric generator actually to be made commercially available in the United States," the unit is designed as "ultra-reliable and unmanned source of power" for radio communications, sea and air navigational aids, and industrial and scientific instrumentation in remote areas where other sources of electricity are not available or—as in the case of batteries—have a short life span and must be replaced or recharged.

The generator is expected to be priced at $500 or less in large-scale production quantities, it was stated, and will be available to both government agencies and industry at large. Single "evaluation samples" are available at a price of approximately $5,000.

The new generator (which employs "thermopiles" of semiconductor elements to convert the heat of the burning propane into electricity) produces five watts of power, steadily and continuously, for as long as the fuel supply lasts, it was stated. It has been designed to run for approximately a year on a 200 pound tank (50 gallons) of propane gas, which sells commercially for about five cents a pound. By

(Continued on page 146A)

FORECAST

Laboratories for space science at Martin are now studying and forecasting the physical, psychological, and biological factors that will affect man in space...another tremendously fascinating program which attracts persons with exceptional professional abilities. If you have these abilities, you are invited to communicate with N. M. Pagan, (Dept. DD-11) The Martin Company, P. O. Box 179, Denver 1, Colorado.

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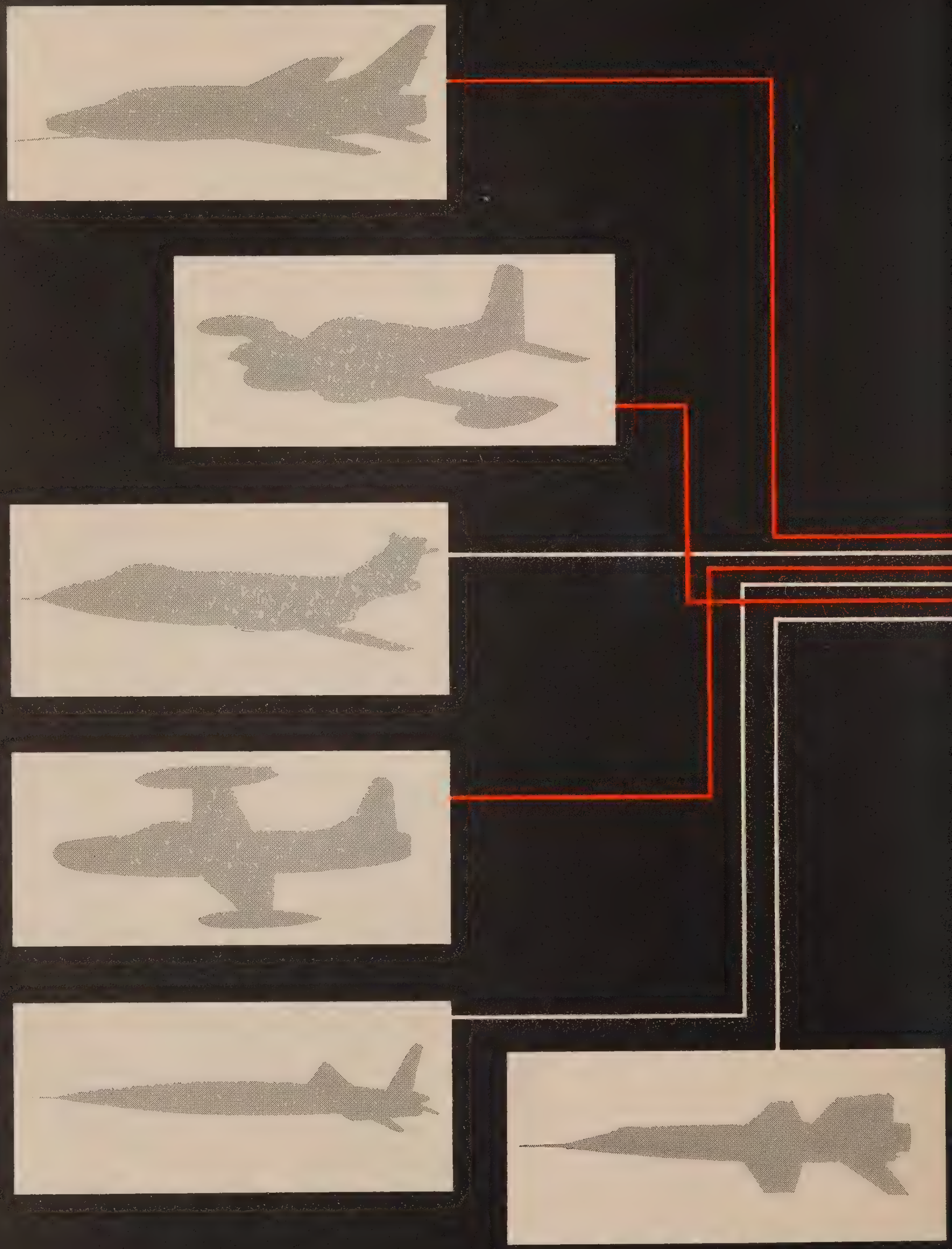

working . . .
with systems that know how to adapt

Like man—Honeywell's Adaptive Autopilot can accommodate, in fact, can adapt. Anthropomorphic? Perhaps—nonetheless, this system has the capacity to change its own parameters through an internal process of measurement, evaluation, and adjustment. It operates independently of air data information and complex gain scheduling—and is unaffected by changes in aerodynamic characteristics. Simply, it adjusts itself in response to its own performance.

Without major modifications, the Adaptive Autopilot can be adapted to air vehicles of all types—from business aircraft, helicopters, drones, supersonic fighters and bombers, and missiles—to the latest hypersonic research vehicles.

Adaptive flight control systems are another example of Honeywell Aeronautical's accomplishments in advanced control. Other developments include electrically suspended gyros, guidance control and environmental control systems, and "decision-making" pre-launch checkers. The division's competence has been demonstrated by contributions to Sergeant, Thor, Atlas, Titan, Polaris, Centaur, Wagtail, F-104, B-58, WS 117L, X-15, F-101, B-66 and WF2. Current expansion has created openings for engineers and scientists in these and similar programs throughout the country and abroad.

*ples of the variety of air-
and missiles that can be
with Honeywell Adap-
utopilots*

living . . .
with people that know how to live

Honeywell engineers and their families find facilities are readily accessible for the things they enjoy.

For the sports minded, the Twin Cities offer Big Ten Football, professional hockey, and in 1961, National League Football. And with its Metropolitan Stadium, one of the country's finest baseball parks, major league baseball seems inevitably near.

Outdoor enthusiasts enjoy this area for its easy access to hunting, fishing, golfing, tennis, swimming, boating—or in winter, skating, skiing, sledding, ice fishing, and ice boating. And the popularity of sailing and yachting is evidenced by the existence of many fine clubs of this type.

Those who appreciate the arts enjoy the Twin Cities as a cultural center . . . listening to the Minneapolis Symphony Orchestra—browsing through the Minneapolis Institute of Art or Walker Art Center—enjoying opera and ballet at Northrup Memorial Auditorium, or legitimate theatre at one of the area's fine playhouses.

These are some of the activities that make this an area for "living." And they're an important part of the life enjoyed by Honeywell engineers and their families.

Inquiries on opportunities with Honeywell Aeronautical will get prompt and confidential attention. Write Mr. James H. Burg, Technical Director, Dept. 662A, Aeronautical Division, 1433 Stinson Blvd. N.E., Minneapolis 13, Minnesota.

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To explore professional opportunities in other Honeywell operations coast to coast, send your application in confidence to H. K. Ekstrom, Honeywell, Minneapolis 8, Minn.

3-Question Quiz for Senior Level Electronic Engineers and Physicists

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(2) Do you have a high degree of respect for your top management's technical competence?

(3) What about the projects you're working on—are they stimulating enough to fully challenge your talents?

At General Mills R and D Laboratories in Minneapolis, engineers and physicists answer an enthusiastic "yes" to all these questions.

For nearly two decades we have been developing and manufacturing weapons, sub-systems, and electro-mechanical and electronic instrumentation systems for both military and commercial use. Our growth has been impressive, and it promises to be even more impressive. Right now we have several technical supervisory and purely technical opportunities open to senior level engineers and physicists in the fields of:

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- Electronic Circuit Design
- Micro-wave Development
- Digital Computer Logic
- Electronic Packaging
- Advanced Pulse and Video Circuit Development
- Advanced Inertial Navigational System Development
- Optical and Infra-Red Equipment Engineering

Perhaps you are one of the men we seek. Ideally, you have a graduate degree and 5 to 8 years experience in electronic instrumentation systems development. In any event, if you now hold a technical supervisory position or are capable of doing so, if you have initiative and drive, if you enjoy exploring the unknown in order to find better ways of doing things—we are genuinely interested in you. And you should be interested in us, because we promise you a creative environment in which you can quickly achieve the full measure of professional and personal recognition that your finest talents demand.

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NEWS New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 143A)

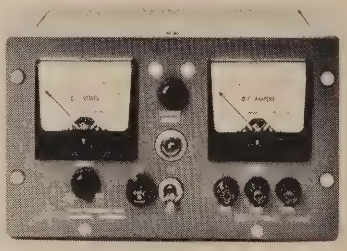
storing 1,000 pounds of propane gas with the generator, it could run unattended for five years, according to General Instrument engineers.

The thermoelectric power plant, which looks like a small cylinder 12 inches high and 12 inches in diameter, has at its center a specially-designed, burner that burns the propane gas at a constant temperature and uses more than 85% of the heat content of the fuel. Surrounding the burner is a metal combustion chamber which captures the heat. Attached to each of the four sides of the combustion chamber are the "thermopiles." The heat not used by the thermopiles is conducted directly to "heat rejection fins" made of aluminum, which form the outer shell of the whole unit and give it a star-like appearance.

The five watts of power produced, it was pointed out, is the same amount of electricity as is used to run the radio on the Pioneer V satellite, sending messages from hundreds of thousands of miles in outer space. It also is the same power as was produced by the experimental SNAP III atomic thermoelectric generator unveiled at the White House in January, 1959. Melvin Barmat, who was Project Manager for the Martin Company on SNAP III, established and heads up the General Instrument Thermoelectric Division and was largely responsible for design and development of the new device.

Dual Range Power Supply

Invar Electronics Corp., 323 W. Washington Blvd., Pasadena, Calif., announces development of a transistorized power supply featuring dual range operation. It is known as the Model TP-36/18 Dual Range Supply.



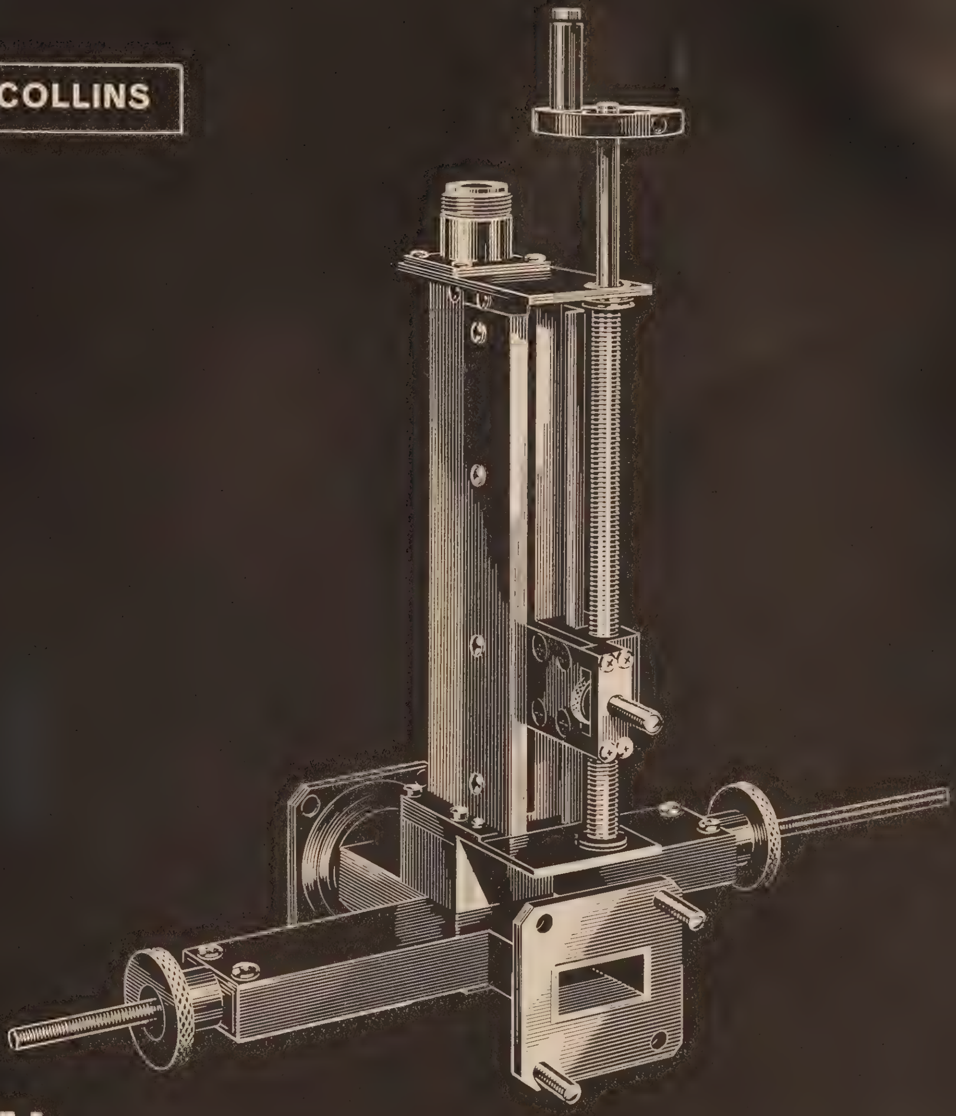
The Model TP-36/18 provides a front panel switch for selecting either of two ranges of operation. The supply will deliver up to 2 amperes at 0 to 18 volts in the first range; and up to 1 ampere at 0 to 36 volts if operated in the second range.

In either range line regulation is 10 mv, load regulation is 5 mv and ripple is 0.2 mv rms.

Model TP-36/18 also features complete electronic short circuit protection, remote programming and remote sensing.

(Continued on page 148A)

RESEARCH AT COLLINS



THE UNUSUAL SHAPE OF PROGRESS

A company sponsored research program to investigate the operation of parametric amplifiers has resulted in improved communication equipment in the uhf frequency range. Collins engineers decided to attack the problem from the standpoint of circuitry rather than device design, and the two-port uhf parametric amplifier shown above emerged from Collins Research Laboratories. Final development resulted in an amplifier with a gain-bandwidth product more than twice that of previous amplifiers.

In the Advanced Circuits Division of Collins Research Laboratories, physicists, mathematicians and engineers are planning basic research programs in solid state physics. Research in the field of thermoelectric phenomena is now in progress. Other studies are being conducted in this division in the general area of modulation and information theories, and traveling wave principles. To further this work, and to advance scientific knowledge with the resultant development of new technologies in other areas, unique professional opportunities are now being offered by Collins Research Division in radio astronomy, advanced circuits, advanced systems, antennas and propagation, mechanical sciences and mathematics. Your inquiry is invited.

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SERVOS

The IBM Research Center in Westchester County, New York, has an excellent opportunity for a senior electrical engineer with broad theoretical and practical experience in servo controls and servo components. Problems involved in this assignment include control of high-speed tape transports, control of pulse hydraulic circuits, and analysis of nonlinear analog systems.

You should be familiar with basic electrical, mechanical, and hydraulic servos and components, as well as analog circuit systems. You should have a working knowledge of standard linear servo techniques—such as root locus, Nyquist, Bode, Z-transform, and sample-data systems. Familiarity with the latest work being done on nonlinear servos is desirable.

QUALIFICATIONS:

M.S. or Ph.D. in Electrical Engineering plus considerable experience.

You will be working with people who are outstanding in their respective fields. You will be eligible for many liberal employee benefits, including a comprehensive education program. This is an outstanding opportunity to work on interesting and challenging research problems.

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Yorktown Heights, New York

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(Continued from page 146A)

Two units can be mounted side by side in a 19-inch rack, 5¼ inches high, for operation as a dual supply; or, if operated in series, to provide wither 0–36 volts at 2 amperes, or 0–72 volts at 1 ampere.

The unit sells for $275.00, with delivery from stock.

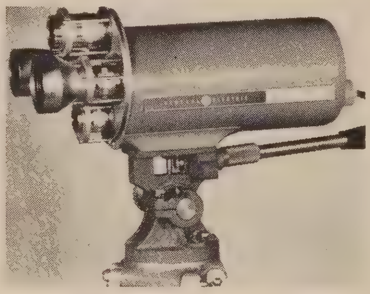
Invar Electronics is a subsidiary of Telemeter Magnetics, Inc.

For further details write to the firm.

Closed Circuit TV Camera

General Electric Co., Technical Products Operation, Communication Products Dept., Electronic Park, Syracuse, N. Y.

Applications for the TE-9-A include the military, industrial and educational fields



Enclosed in a rugged, dust-tight housing the Vidicon unit successfully passed a series of tests in which it was mounted close to several rocket engines.

In all cases, the camera performed continuously with consistent picture quality and withstood the shock and noise without any additional special protective housing. In one test, it was mounted eight feet from the engine in an ambient noise environment in excess of 190 db.

Cylindrical in design, the camera is 110 inches long, has a diameter of 50 inches and weighs nine pounds.

The camera will use virtually any standard 16 mm lens and is equipped with a remote turret for mounting four lenses at one time.

Remote optical focus, turret and iris accessories are available, and drive mechanisms are enclosed in the camera.

Other accessories include a remote zoom lens, small pan and tilt, large pan and tilt, remote control unit and remote douser.

The TE-9-A achieves high picture quality—Horizontal resolution is 650 lines, which is considerably above broadcast studio requirements. It will operate effectively at extremely low light level.

The camera's low power operation—achieved through extensive use of transistors—makes ventilation unnecessary. Power input is 18 watts. The camera provides a 1.0-volt composite video output to any monitor. In scanning, it uses 525 lines, 2:1 interlace and 60 cps field rate. The TE-9-A has maximum sensitivity and

(Continued on page 150A)

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ELECTRONICS ENGINEERS

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AC Seeks and Solves the Significant—AC has earned an enviable reputation for scientific accomplishment with national defense projects such as AChiever inertial guidance systems. But AC is not limiting its goal to leadership in the international technological race. Utilizing scientific "fallout," AC is also increasing its development of significant new commercial products. / This, too, is AC QUESTMANSHIP: the scientific quest for new ideas, methods, components and systems . . . to promote AC's many projects in guidance, navigation, control, detection and communication. / In the commercial field, AC is already producing communications systems, automotive controls and fuel controls for gas turbine engines. Some day they may even add such advanced projects as systems controls for "ground effect vehicles." According to Mr. B. H. Schwarze, AC Director of Commercial Engineering, "the proper application of scientific 'fallout' to commercial products leads to diversified career opportunities." / You may qualify for our specially selected staff . . . if you have a B.S., M.S. or Ph.D. in the electronics, scientific, electrical or mechanical fields, plus related experience. If you are a "seeker and solver," write the Director of Scientific and Professional Employment, Mr. Robert Allen, Oak Creek Plant, 7929 So. Howell Ave., Milwaukee, Wisc.

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NRL

U. S. Naval Research Laboratory
WASHINGTON 25, D. C.

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 148A)

can be used down to 1.0-foot candle scene illumination. It operates over 80°C temperature range.

The cover is removed by loosening two captive fasteners and sliding it off the rear of the unit. This exposes the component side of all chassis and permits circuit checking at the component eyelets. Circuitry uses only one tube. The main power fuse is accessible at the rear bottom.

Silicon Alloy Transistors

Western Transistor Corp., 13021 S. Budlong Ave., Gardena, Calif., revealed development and production of a new series of P-N-P silicon alloy transistors, carrying the trade name "WesTran." The '327' series is designed for switching and general purpose application at low and medium power levels. They are suited for use in audio, servo, and dc amplifiers.

The series has been engineered to exceed Mil Spec T-19500, in that they are more structurally rigid than required in such environmental conditions as acceleration, shock, impact, and thermal fatigue.

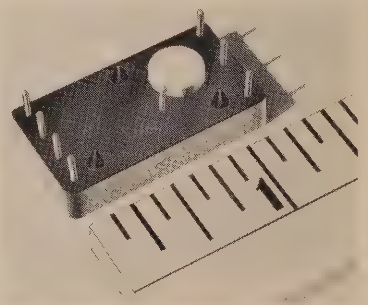
WesTran's facilities were established in January this year, located in a growing industrial suburb of Los Angeles. Their output will shortly reach several thousand units per day. Initial deliveries in quantity were scheduled for April 15. Plans for the near future include introduction of a new high frequency double diffused transistor (mesa), to be produced by early summer.

President and General Manager Charles Prawdzik formerly headed transistor product engineering at Hughes Products, Semi-Conductor Division.

Data brochure 2N327A will be sent on request.

Logic Circuit Unit

A new balanced resistor network designated the SPR-76, which measures only $1\frac{1}{4} \times \frac{11}{16} \times \frac{1}{4}$ is available from **Dale Products, Inc.,** Columbus, Nebraska. The network contains five precision wire wound resistors and one transistor incorporated into a NOR logic circuit.



The complete circuit is encapsulated in a rigid epoxy compound. The network is

(Continued on page 152A)

COMPUTER engineers*

* The acceptance by business and industry of the Philco 2000 All-Transistor Data Processing System has created a number of significant advancement opportunities in our organization both at our new headquarters in suburban Philadelphia and at various key locations in other parts of the nation. You are invited to call, write or visit us to discuss your future in our growth organization.

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Circuit Designers—Opportunities for experienced engineers at Senior, Project and Specialist levels to work in advanced electronic circuitry for digital computer core and drum memory elements.

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Personnel Dept. IR-4

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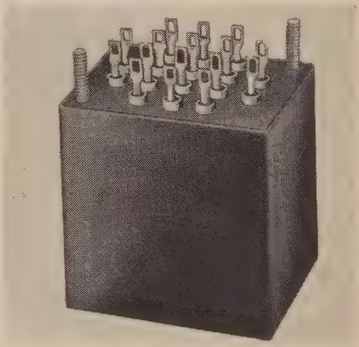
(Continued from page 150A)

designed to withstand tough moisture, temperature cycling, vibration and life tests. Termination is ideal for printed circuit or plug mounting.

For further information on the SPR-76 and other precision networks, write to the firm.

Magnetic Modulator

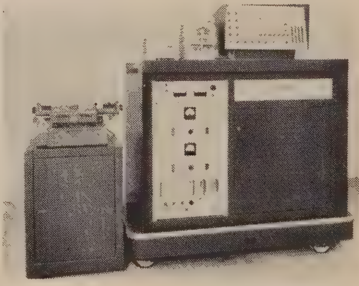


This unit is essentially a low-power level magnetic amplifier. The modulator shown has an input of 115 volts at 400 cps and an output of from 0 to 3 volts and 0 to 2.5 volts with a reversible phase. The dc signal input is 0 to ±100 microamperes, with a 20% maximum distortion of output. The load of this unit is 12,000 ohms.

For further information on this and other magnetic modulators write to **Freed Transformer Co., Inc.,** 1718 Weirfield St., Brooklyn (Ridgewood) 27, N. Y.

Data Logger System

A new Data Logger system that automatically balances from one to 1000 bridges and logs their millivolt output signals in a programmed mode has been developed by **Consolidated Systems Corp.,** a subsidiary of CEC/Bell & Howell, 360 Sierra Madre Villa, Pasadena, Calif.



The system samples 210 channels of analog data per minute sequentially, commutates and converts them, and punches tabulated data in a paper tape at the rate of 60 five-digit characters per second. The punched tape can be input to an off-line printer.

(Continued on page 154A)

Minuteman

...Another major USAF weapon system in development

Minuteman, a three-stage solid propellant intercontinental missile, is moving through its early development and test programs on or ahead of the time schedule originally set for it. This advanced ICBM, the fourth in a family of four Air Force ballistic missiles, is designed to be fired automatically from underground silos or mobile launchers. Minuteman will be constantly at "ready" giving America an almost instantaneous retaliatory capability for defense • The Minuteman concept developed early in 1957 when Space Technology Laboratories conducted a study of the characteristics of second-generation missiles to satisfy the requirements of the Air Force Ballistic Missile Division. STL provides over-all systems engineering and technical direction for Minuteman as it has for the Atlas, Titan, and Thor programs. The application of compatible components, systems, and experience developed through the years is bringing Minuteman closer to the threshold of operational capability • Among the industrial organizations developing Minuteman are such major contractors as: Boeing Airplane Company for assembly and test; Thiokol Chemical Corp., Aerojet General Corp., and Hercules Powder Company for engines; Autonetics, a Divisionof North American Aviation for guidance; and Avco Corp. for re-entry vehicle.

To assure continued growth in these and related space programs, STL is already projecting state-of-the-art advances five and ten years ahead. Outstanding scientists and engineers with unusual capabilities in propulsion, electronics, thermodynamics, aerodynamics, structures, astrophysics, computer technology, and other related fields and disciplines are invited to investigate positions at STL. Please send resumes to:

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..... there are opportunities at Honeywell Aero for the engineer or scientist who is interested in participating in this growing field of technology. While specific inertial systems experience is desirable, you may also be qualified by your background and/or related experience for activities in the inertial systems development at this time. Specific openings include:

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Mathematician or engineer with strong background in vector analysis, operational calculus, matrix algebra and related techniques. To carry out analysis of inertial systems configurations including error evaluation.

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Familiar with digital logic techniques at current state of the art; capable of organizing computing systems to perform various tasks including logical design and critical parameter specification.

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Electrical engineering degree plus experience in miniaturized semiconductor electronics development. To design servo, pickoff, and other electronics for use with gyros and accelerometers.

ENGINEERING PHYSICIST

Physicist with practical and theoretical understanding of mechanics, magnetism and electricity to analyze and develop inertial sensors of novel and original design.

To discuss these or other openings, write Mr. R. O. Maze, Chief Engineer, Marine Systems Group, Dept. 662C. Aeronautical Division, 1433 Stinson Blvd., Minneapolis 13, Minn.

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To explore professional opportunities in other Honeywell operations coast to coast, send your application in confidence to H. K. Eckstrom, Honeywell, Minneapolis 8, Minnesota.

NEWS New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 152A)

All necessary equipment for sampling, amplifying, commutating, digitizing, and punching paper tape is in an integral cabinet.

Although the system can accept any quasistatic signal from zero to 500 millivolts, such as from thermocouples or potentiometers, because of its automatic bridge balancing feature it is recommended for use where 100 or more bridges are used in static testing. An actual application is static testing of aircraft scale models.

The balance mode is programmed with a punched paper tape. During operation in the balancing mode, the system automatically balances the bridges by switching across each bridge a graduated set of precision resistors, and punches the amount of offset onto a second paper tape, called the "run tape." Also punched onto this tape are such calibration and program data as channel selection, selectivity and zero offset. Channels can be omitted or balanced in any sequence, making it possible to repeat channels carrying rapidly changing data during the "run" mode.

Sensitivity control is in increments of 0.01%, for a total of 10,000 increments. These can be directly correlated for a linear scale factor by depressing selected pushbuttons representing four digits to 9999. Sample reading is then in engineering units.

Accuracy of ±0.15% full scale and resolution of five microvolts are built into the system.

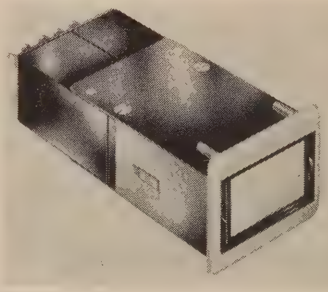
Magnetic Amplifiers

PREAC
AMPLIFIER
AIRPAX
TYPE M-5851-C
FORT LAUDERDALE, FLA.

With thermocouple, strain gauge, photocell or other low level inputs, these 400 cps amplifiers can deliver 0 to ±5 volts output into a 50 K load at accuracies of 0.1% in a single stage of amplification. Series 5800 PREAC magnetic amplifiers are built by **Airpax Electronics, Inc., Seminole Div.,** Fort Lauderdale, Fla. They feature a built in temperature compensation, a filtered output and inherent high gain and reliability. These dc amplifiers are applicable to ground multi-channel data amplification and airborne instrumentation and are employed as highly reliable and flexible building blocks in instrumentation and control systems. Applications also include linear amplification, null and error detection, summing with electrical isolation, integrating, micro-volt and microampere measurement.

Switch Light

A switch light which rebulbs from the front without use of tools, features all terminals at back of the assembly, and can use 115V ac to operate AN-3140-327 bulbs in its small package is available from **Master Specialties Co.,** 956 E. 108th St., Los Angeles 59, Calif. Lamp and switch circuits are independently operated.



The lens area can be subdivided into four segments. Units are easily wired, and mount flush. Units and switches qualified per Mil. Specs. Positive tactile sensation on activation. Solid shake-proof mounting with impact resistant construction. Bulbs remain stationary during switching. Light intensity is bright and uniform. Units can include components for diode test. They may be grouped with standard Roto-Tellite^{R} units. Ambient temperature range is −65°F to +160°F.

Solid State Power Supply Modules

The Model PS 202, an inexpensive, compact dc supply with dual output up to 150 milliamperes at ±18 volts or a single output at ±36 volts, is available from **Solidyne,** 7640 La Jolla, Calif.

Line and load regulation is ±1% with less than 6 millivolts of ripple. This 8″×3″×3″ unit weighs 2 pounds and is convenient for bench work as well as the building block of transistor equipment.

Model PS 206 is primarily used where a dc reference source is required. Line regulation from 95 to 135 volts ac input is 0.1% with continuously variable dc output of 2 to 24 volts. Load regulation is 0.1% with loading of 0 to 100 milliamps. Temperature stability is 50 parts per million/°F in the range of 40 to 120°F. Line-Load isolation

(Continued on page 156A)

YOUR IDEA MAY BE BOEING / WICHITA'S PRINCIPAL FUTURE PRODUCT!

If you're the kind of man with a truly inventive turn of mind . . . if you have really big ideas about end products and processes . . . if you can sense the challenge in joining one of the world's largest companies at the beginning of an expansion and diversification push . . .

YOU BELONG WITH BOEING / WICHITA Here's why: We have started the most ambitious product development program in our history. As you probably know, the tools are already here. Boeing / Wichita is one of the most extensive design and manufacturing complexes ever put together . . . with test facilities to match.

We're looking for the kind of brains and vision that can activate meaningful programs in New Product Design. We're looking for the few men whose original thinking today will be translated into the products of an advanced age tomorrow. The rewards will be great. In terms of challenge, nothing can surpass it. Materially, basic compensation will be excellent . . . and Boeing's well-known royalty plan is spelled out in black and white.

Naturally, the qualifications are high. But if you are one of the few who fits them . . . by education, experience, inherent ability, or a combination of these . . . you will probably know it instinctively. We invite you to write in confidence to Mr. Melvin Vobach, Dept. H6, Boeing Airplane Co., Wichita 1, Kansas.

BOEING / WICHITA

CAREER OPPORTUNITIES WITH BAUSCH & LOMB

Section Head, Electronic Engineering

7 to 10 years experience, with design capabilities in circuits, controls, servos, feedbacks, etc.

Physicists

- Ph.D. or equivalent; creative development of optical electronic measuring systems.
- Experience in spectroscopy and electronics.

Electronic Engineers

- Senior designer, circuit capabilities, supervisory experience.
- Experience in acoustics or tape recorder engineering.
- Experience in circuit design and development of servo-mechanisms.
- Experience in scientific instrument design.
- Experience in design of photo-electric measuring systems.

Reply, with resume, to Mr. Ellis P. Faro, Employment Manager, Bausch & Lomb, 635 St. Paul St., Rochester 2, N.Y.

NEWS New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 154A)

is in excess of 10k megohms. Module dimensions are 7.5×3.5×2.5″. Model PS 206 finds application in the strain-gauge instrumentation field.

New Literature

A four-page application note describing the use of the Moseley Model 60B Logarithmic Converter as a computing element is now available from the company.

The note explains how the 60B, when used in pairs and with a suitable read-out device, can readily perform multiplication and division. Any read-out device may be used, provided the complete load impedance agrees with the values presented in the application note's diagrams and tables.

The application note, AN-101, may be obtained by writing the **F. L. Moseley Co.,** 409 North Fair Oaks Ave., Pasadena, Calif.

Portable Temperature Chamber

A precision temperature test chamber capable of accommodating rack-mounted electronic equipment has been announced by **Delta Design, Inc.,** 7460 Girard Ave., La Jolla, Calif. Prolonged temperature runs with stability to within ½°F over the range −100°F to +500°F can be economically made.

Described as Model 7000A, the chamber has an internal test volume of 19½×11 ×15 inches, easily handling the 19-inch standard rack unit. Model 7000A attains its high degree of temperature stability through the use of a thermocouple and a precision meter-relay.

With an auxiliary timer-control unit, Model 7000A can be pre-set for automatic hot-cold cycling at alternate temperature levels throughout the chamber's—100° to 500° F range. The auxiliary timer is available as optional equipment. The chamber control is not subject to drift due to line voltage variations even on prolonged runs.

The aluminum cabinet of the Model 7000A is finished in gray wrinkle enamel; the interior is of stainless steel. Liquid CO_2 is used for cooling. The chamber is supplied with a Pyrex window for visual observation, and a large access port accommodates all feed-through connections.

CLEVITE
REQUIRES THE TALENTS OF . . .
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Silicon Mesa Transistor Engineers

OUTSTANDING FRINGE BENEFIT PROGRAM

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CITIZENSHIP NOT REQUIRED

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Engineering Placement Director

CLEVITE TRANSISTOR

Waltham 54, Mass. — Tel: TWinbrook 4-9330

DEVELOPMENT ENGINEERS

This is an opportunity for advancement in an expanding engineering department.

For quality transformers, chokes, regulators and other magnetic devices used in electronic measuring instruments.

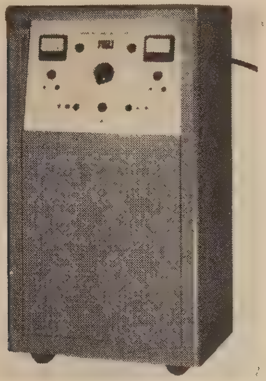
An engineering degree is required as well as experience in design with responsibility for the performance of the equipment.

Please write or call
Mr. J. P. Van Duyne,
Engineering Mgr.

BOONTON RADIO CORP.
BOONTON, N.J. DEERFIELD 4-3200

D3 Power Supply

A new dc power supply delivering 200 ma at 25 kv for experimental and industrial applications is announced by **Del Electronics Corp.,** 521 Homestead Ave., Mount Vernon, N. Y.



Model PSC 25-200-2 is designed for 208 volt, 3-phase 60 cps operation. Incorporated are several outstanding safety features: no exposed high voltage components; zero-start interlock; over-voltage and overcurrent relays; fully adjustable voltage output on front panel; completely self-contained—all high voltage components immersed in tank of high grade insulating oil; push button "on-off" controls.

Descriptive material on Model #25-200-2 can be obtained by writing to the manufacturer.

Transistorized Instruments

A complete line of transistorized regulated power supplies, dc-dc voltage regulators and a transistor checker is announced by **Valor Instruments, Inc.,** 13214 Crenshaw Blvd., Gardena, Calif. All are designed for transistor circuit applications and are explained with applications, specifications and prices in catalogue SF 1259.

Fifteen power supplies with outputs of 1.5–50 vdc and 0–5 amperes, four voltage regulators with outputs ranging from 6–35 vdc and inputs 24–45 dvc plus a transistor checker designed for fast (10 second) tests are fully explained.

Panel Meter Bulletin

The "Big Look" In Small Panel Meters—Bulletin GEA-7034, 12 pages, four colors, offers complete descriptive and buying information on General Electric's line of 2½-, 3½-, and 4½-inch "Big Look" panel meters. Includes a detailed description of product features and specifications, plus dimensions, prices, and ordering instructions for all available instruments. A description of custom features for special applications is also included. **General Electric Company,** Schenectady 5, N. Y.

Rack and Panel Connectors

A new Series DTD Rack and Panel Connectors is being announced by **H. H. Buggie Div., Burndy Corp.,** P. O. Box 817,

(Continued on page 158A)

ACF ELECTRONICS DIVISION
ELECTRO-PHYSICS LABORATORIES

Responsible assignments in furthering the state-of-the-art of Ionospheric Physics, combining competitive salaries and unusual growth potential, are offered to men who can contribute. Our present needs are for:

Physicists
Electronic Engineers
Field Station Engineers

FOR RESEARCH PROGRAMS IN
IONOSPHERIC PROPAGATION
& HF COMMUNICATIONS

SENIOR IONOSPHERIC PHYSICISTS

Ph.D. preferred, with several years' experience in the study of Ionospheric phenomena. Should be familiar with present knowledge of upper atmosphere physics and possess an understanding of current programs using rockets and satellites for studies in F-region and beyond. Qualified individuals with supervisory abilities will have an exceptional opportunity to assume project leadership duties on HF projects already under way involving F-layer propagation studies backed by a substantial experimental program.

SENIOR DEVELOPMENT ENGINEERS

Advanced degree in E.E. or Physics preferred. Must be familiar with present state-of-the-art in the design of advanced HF receivers and transmitters and possess working knowledge of modern HF networks employing ferrites and metallic tape cores. Strong theoretical background in modern linear circuit theory desired. Will carry out laboratory development and implementation of new HF communication systems.

SENIOR ELECTRONIC ENGINEERS

Advanced degree in E.E. preferred. Must be familiar with conventional pulse circuit designs and applications. Technical background should include substantial experience in data process and data recovery systems using both analog and digital techniques. Knowledge of principles and application of modern information theory including correlation techniques helpful. Will be responsible for the design of sub-systems.

JUNIOR ELECTRONIC ENGINEERS

To assist Senior Engineers and Scientists in the development of HF communications and data process equipment. Should have formal electronics schooling and 2 years' experience in circuit design, checkout or analysis of HF communications, Radar Pulse, Analog/Digital or Data Recovery equipment. Construction of prototypes of new and interesting equipment and design of individual components of communications and data processing systems will comprise the major efforts of selected applicants.

FIELD STATION ENGINEERS

B.S.E.E. or equivalent, consisting of combined civilian or military technical school, with work experience. Presently employed as a field engineer or project engineer with valid 1st or 2nd Class FCC license and a good command of some of the following: Radar, preferably high power; HF long-distance communications systems; Tropospheric or Ionospheric scatter systems. Must be willing to accept assignments in areas where dependents are not permitted for periods of up to one year. Differential paid for overseas assignments.

The Electro-Physics Laboratories are located in the suburban Washington, D.C. area, where post-graduate study is available in several nearby universities. Housing is plentiful in attractive, well-established neighborhoods. Our relocation allowance is liberal.

All inquiries will be held in strictest confidence and answered promptly.
Please send resume to:
PROFESSIONAL EMPLOYMENT DEPARTMENT
ACF ELECTRONICS DIVISION
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Industries, Incorporated
Riverdale, Maryland

men with ideas

are needed at HRB-SINGER in the following professional areas:

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HRB offers the opportunity to work on vital electronic problems; an attitude of research emphasizing freedom of expression; a location combining the cosmopolitan atmosphere of a city with the advantages of small-town living. Through the tuition-refund plan employees are encouraged to pursue graduate study at the nearby Pennsylvania State University. Write in confidence to Personnel Director, Dept. R-3, HRB-SINGER, INC.

HRB-SINGER, INC.

Science Park, State College, Pa.

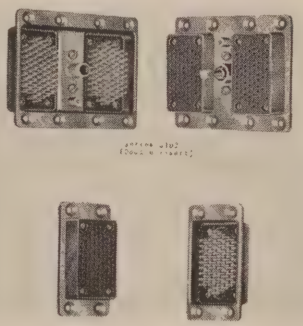
A SUBSIDIARY OF

THE SINGER MANUFACTURING CO.

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 157A)

Toledo 1, Ohio, for military, commercial and industrial equipment application.



Series DTD is being offered with single or double inserts mounted in a die-cast aluminum alloy shell. The compact design permits a large number of contacts in a small area. At the present time, tooling has been completed on the 50 and 78 contact inserts, making available for immediate production connectors with 50, 78, 100 and 156 contacts, or combinations of these inserts. Other standard insert arrangements are being tooled and will be announced to the industry as completed.

An advantage of the Buggie Series DTD connectors is that either male or female inserts are interchangeable in the field as a sub-assembly. The insulating material for the inserts is Melamine. It provides a rigid insert and meets Military Specification MIL-M-14E, Type GMG. Contacts are brass (pin) and phosphor bronze (socket). Silver and/or gold plating is provided.

The double insert Series DTD2 utilizes a screw fastener for quick engagement and disengagement. This fastener can be furnished with wing or Allen head. Also, connectors will be furnished without an engagement device.

The company has available a catalog specification sheet giving complete description and dimensional data for design-specification engineers.

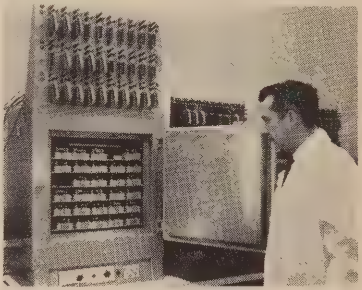
Range Converter For Recorder

A new 4-page Data Sheet NY2(1) "Speedomax H Range Conversion," available from **Leeds & Northrup Co.,** 4934 Stenton Ave., Philadelphia 44, Pa., provides a guide to selecting the necessary components—scale, chart, circuit panel, etc.—to change the range of any standard Speedomax H instrument.

A master table on the sheet lists the basic items required to change range (1) for the same type of primary element, or (2) from one type of primary element to another (e.g., thermocouple to Rayotube detector). Individual tables list the specific part numbers of scales, charts, etc. for each type of range. Wiring diagrams to simplify electrical connections are also listed.

Component Life-Test Oven

A new elevated-temperature thermostatically controlled life-test oven with complete internal power-supply and test-facility circuitry has been introduced by **International Telephone and Telegraph Corp., Components Div.,** 815 San Antonio Rd., Palo Alto, Calif. The new unit handles 660 bipolar components or 330 tri-polar devices. Standard units are rated at 125°C maximum.



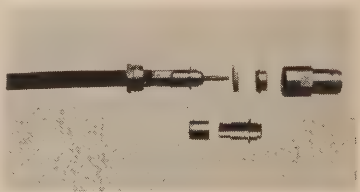
Components are carried in low-resistance electrical clips on mounting racks of expanded metal. These have self-mating connectors on their rear surfaces and the related circuitry permits either connection of all racks to a common power supply or each to an individual one.

This Teflon-insulated wiring terminates in a patch panel above the oven, by means of which electrical checking of the components under test can be performed externally without disturbing the internal temperature by opening the oven. Test circuitry is rated at 750 volts and 5 amperes with resistance less than 0.5 ohm.

Power requirements are 1600 watts at 115 or 230 volts and 50 or 60 cps. Weight is 250 lb. Prices start at approximately $4,000.

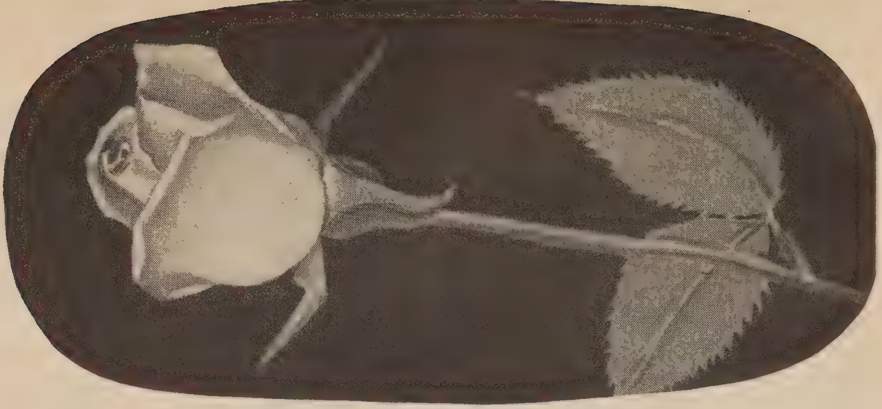
Coax Connector Attaching Device

A new method for attaching RF connectors to coaxial cable is now manufactured and available from **Kings Electronics Co., Inc.,** 40 Marbledale Rd., Tuckahoe, N. Y., under license from Douglas Aircraft Corp. This method embodies the use of Kings' K-GRIP and offers many features not to be found in conventional connectors.



K-GRIP connectors have several advantages. Connector parts can be readily removed for inspection or replacement in the field without disturbing or impairing the electrical characteristics of the cable assembly. Both the cable braid and the dielectric are firmly held by the device resulting in a stronger connection. K-GRIP eliminates the need for a captive contact. These grips for Type RG-8/U cable can be

(Continued on page 160A)



At Bendix York, we have a number of immediate openings for Electronic Engineers and Physicists.

There are many worthwhile advantages awaiting the Professional Engineer who chooses to advance his career with us at Bendix York.

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The white rose is a symbol at Bendix York . . . a symbol with two meanings. Both of vital importance to *your* future.

First, the white rose is the official flower of York, Pennsylvania. It is a symbol of the good life in our dynamic community, located in the heart of the scenic Pennsylvania Dutch region. It is a wholesome, happy area with excellent schools, delightful recreational opportunities and many cultural advantages. Here—away from high-pressure, high-cost, big-city living—you will enjoy the fuller, more rewarding life that you want for yourself and for your family.

Second, the white rose is a symbol of perfection . . . the perfection for which we strive at Bendix York—perfection in the engineering and scientific pioneering and development in missile electronics that is our principal objective.

We offer a small Division's assurance of individual recognition and advancement, and yet you have the security and employee benefits of a large corporation.

We would like to have the opportunity to tell you more about Bendix® York. We invite you to contact us—by dropping us a post card, by giving us a call or, if you will, by sending us a brief resume. Address Professional Employment: Dept. P

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YORK DIVISION

York, Pennsylvania
Phone: York 47-1951

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Immediate expansion of new and existing programs is creating outstanding opportunities in R&D and PRODUCTION on advanced programs such as:

- **Shillelagh, surface-to-surface tactical missile**
- **Air Cushion Vehicles**
- **Anti-submarine Warfare**
- **Air-to-surface tactical weapons**

Positions are at interim facilities in Santa Ana near Aeronutronic's new $22 million Engineering and Research Center now being completed at Newport Beach, Southern California—the West's most ideal location for living, working and year 'round recreation.

Experienced engineers with demonstrated ability are invited to share in research and development work—work that is challenging and stimulating as well as exceptionally rewarding.
Send inquiries and resumes to Mr. John Starbuck, Dept. 29

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a Division of FORD MOTOR COMPANY
FORD ROAD, NEWPORT BEACH, CALIFORNIA

PHYSICIST
ADVANCE DEVELOPMENT OF SEMICONDUCTOR DEVICES

PhD, MS or equivalent with a background in solid state physics or electronics to analyze the operation of high frequency devices leading to the development of new device structures.

WRITE: M. D. Chilcote, Div. P-6
Semiconductor Products Dept.
Electronics Park, Syracuse, New York

GENERAL ELECTRIC

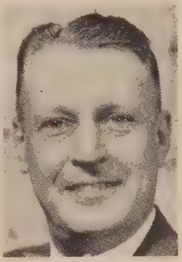
These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 158A)

used with over 50 standard RF connectors. K-GRIP connectors are also available for other standard cable sizes. Assembly is accomplished by means of a readily available inexpensive Thomas & Betts tool. Attaching time of connector to cable is reduced. Soldering may be eliminated on connectors which have brass center contacts because the center contact may be crimped to the cable's center conductor by the same tool.

Super-Temp Names Two V.P.'s

Leroy Tourville, President of **American Super-Temperature Wires, Inc.,** of Winooski, Vermont today announced the appointment of Richard D. Hoyt as Vice President in charge of Sales and Oakley F. Hoyt as Vice President in charge of Market Research and Advertising. The Hoyts, residents of Princeton, N. J., have jointly supervised sales for the company since it was organized in 1955 and have served in engineering capacities as well. In 1958, Super-Temp became a subsidiary of Haveg Industries of Wilmington, Delaware.


O. F. Hoyt

R. D. Hoyt

Both Hoyts have been engaged in the industry for over twenty years, and, during the past decade they have specialized in high temperature wires, employing TEFLON, Silicone Rubber, etc., as insulating compounds.

Richard Hoyt, in his new position, will continue to promote the Super-Temp line on a national basis while Oakley Hoyt will be engaged in the investigation of new product possibilities and broadening the application of the company's present high temperature wire line in the military, industrial and consumer fields.

The Hoyts will continue to operate from the Sales Office at 195 Nassau St., Princeton, N. J.

Hermetic Seals Catalog

A new catalog 1259 which lists basic types of precision hermetic seals which are regularly available for evacuated or pressurized enclosures, is available from **Dage Electric Co., Inc.,** Beech Grove, Indiana. Each type of seal is clearly illustrated and

(Continued on page 162A)

NASA's

2nd, 3rd, 4th generation space rockets

To go vastly greater distances . . .
to send heavier payloads . . .
NASA scientists and engineers are working on the Centaur, Saturn and the Nova type vehicle. As the curve of scientific progress approaches the vertical, these advanced rocket boosters may bring significant breakthroughs in space exploration.

CENTAUR—the first rocket booster to be fueled with liquid hydrogen—will enable NASA scientists and engineers to put four-ton payloads into 300-mile orbits around the earth.

SATURN—initiated by Defense Department and now transferred to NASA, the 1.5 million pound thrust booster will place 15-ton payloads in orbit. Such a payload could be a manned space observatory.

NOVA TYPE—a cluster of single chamber 1.5 million pound thrust engines now being developed to launch multi-ton space stations or to send manned expeditions to the moon.

Scientists and Engineers:

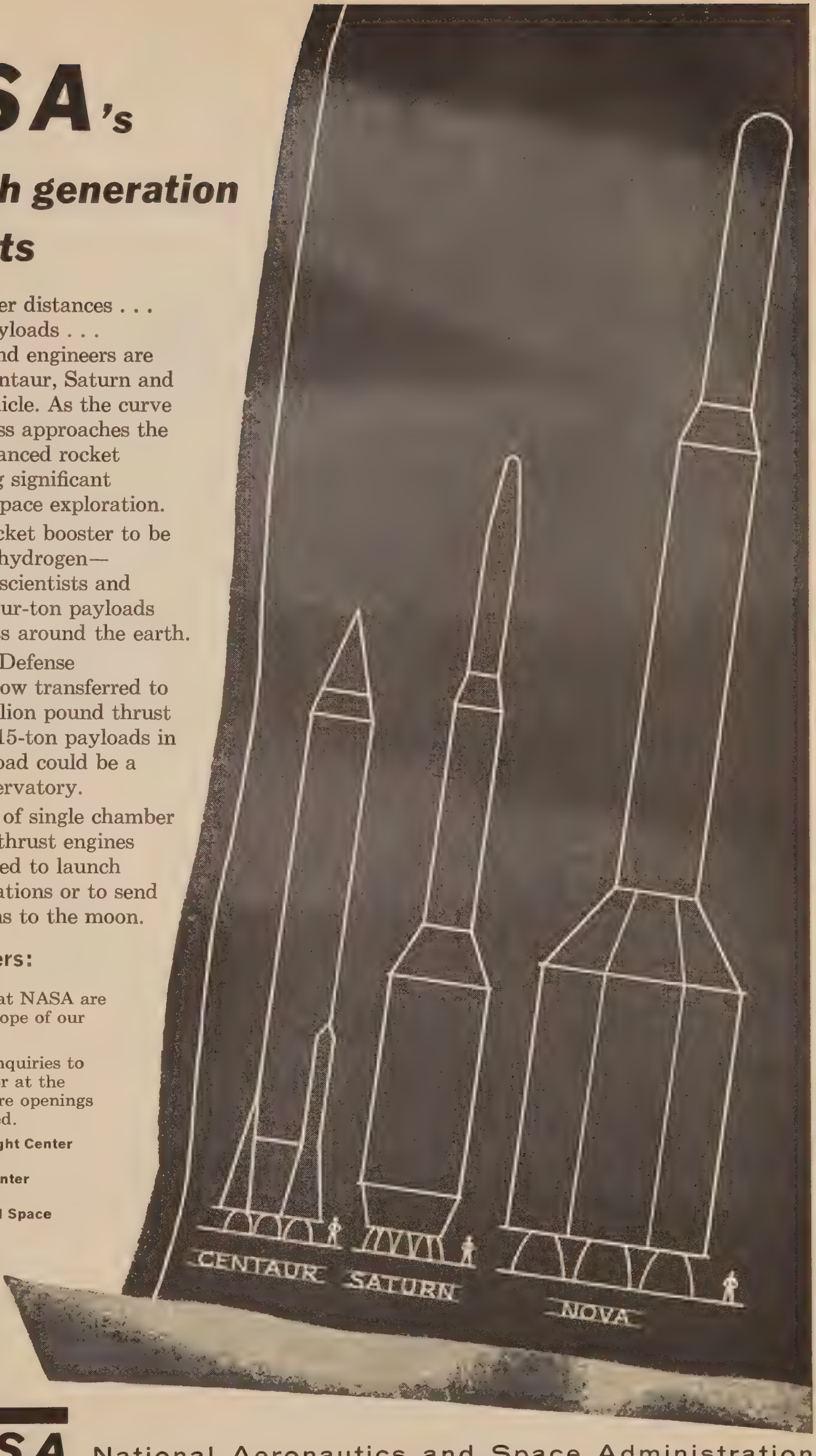
Career opportunities at NASA are as unlimited as the scope of our organization.

Please address your inquiries to the Personnel Director at the following centers where openings exist or are anticipated.

NASA Goddard Space Flight Center
Washington 25, D. C.

NASA Flight Research Center
Edwards, California

NASA George C. Marshall Space Flight Center
Huntsville, Alabama



NASA National Aeronautics and Space Administration

PRELIMINARY DEVELOPMENT

SENIOR ENGINEERING SPECIALISTS

Honeywell Aero Preliminary Development Staff has several openings for technically qualified and mature engineers with significant military system development experience. Each man will provide guidance and support in his specialty to Honeywell design projects for the best use of advanced techniques in development of new airborne systems. These staff positions offer scope for original personal contributions and will require active participation in the formulation and execution of Division engineering programs. Among the openings are:

WEAPON DELIVERY AND CONTROL SYSTEMS SPECIALIST

Background of system and computer development for bombing, fire control, or navigation. Firsthand experience with system analysis, tie-in requirements, analog and digital computers, operations analysis, and weapon effectiveness evaluation.

DETECTION SYSTEMS SPECIALIST

Primary background of airborne radar development in one or more areas such as AMTI, Doppler, pulse Doppler, automatic tracking, and countermeasures. Experience in infrared or communications will be valuable. Experience should include system analysis, design requirements, equipment development, and performance evaluation.

ELECTRONIC CIRCUIT AND PACKAGING SPECIALIST

Background of circuit design for advanced control and computation equipment. Should be familiar with dc, low frequency, pulse and rf techniques. Must be able to establish sound analytical basis for circuit design to specific levels of reliability and performance. Must be experienced with solid state devices and prepared to contribute to Aero Division work on microcircuit techniques.

To discuss openings for these and other specialties, write or phone Mr. J. R. Rogers, Chief Engineer, Preliminary Development Staff, Dept. 662E, Aeronautical Division, 1433 Stinson Blvd., Minneapolis 13, Minn.

Honeywell

Military Products Group

To explore professional opportunities in other Honeywell operations coast to coast, send your application in confidence to H. K. Eckstrom, Honeywell, Minneapolis 8, Minnesota.

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 160A)

listings give complete dimensional specifications.

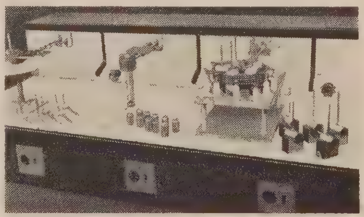
DAGE
ELECTRIC COMPANY INC

A special section gives latest accepted glass seal nomenclature. To assist the designer who requires custom-made seals, the 28-page catalog also covers general manufacturing techniques and usage recommendations. Dage precision hermetic seals are tested to insure unit integrity with respect to moisture, corrosion, extreme pressures, vibration and rare atmospheres.

Copies of the new Dage catalog 1259 may be obtained fron Dage representatives or by writing.

Induction Heating Work Tables

Lepel High Frequency Laboratories, Inc., 55th St. and 37th Ave., Woodside, N. Y., has developed a line of multiple position work tables with built-in power transfer switches for numerous induction heating applications such as; soldering, brazing, bombarding and heat treating.



In the accompanying illustration, the set-up on the left shows a five piece assembly being soldered in one open end coil using pre-formed solder rings; in the center of the table, tungsten contacts are being brazed to brass bodies using silver solder; and on the right, five copper and brass assemblies are being soldered within one heating coil. The three-position work table is powered by a single induction heating generator, which can be switched from one working station to another.

It is ideal for applications that are frequently used. The outstanding feature is the advantage of leaving the operating set-up as is, proceeding to the next application, then returning to the original set-up without loss of time. The work table is equipped with pilot lights to indicate the station being powered. Each station can be operated by a push-button, footswitch or timer. These work tables can also be built with quench tanks for heat treating applications.

Circular Waveguides

Simple and complex bends in millimeter-band circular waveguide are now being fabricated, as the result of a newly developed method of waveguide construction by **TRG, Inc., Antenna and Microwave Dept.,** 9 Union Square, Somerville 43, Mass. The bends are made by first corrugating the inside of lengths of straight copper waveguide and then bending them to the desired shape.

The new method of construction was developed to make use of the TE_{01} mode in circular waveguide, preferred because of its circular symmetry and low loss. The corrugations overcome the problem of deviations from straightness, and the resultant mode conversion to the degenerate TE_{11} mode. In addition, the new method allows complicated bends to be made with little or no machining.

A typical 90° bend made with the new method, Model V-BMM 1, has a three-inch inside radius. The waveguide inside diameter is 0.353 inches. The loss in this particular section is less than 0.2 db. Bends at angles other than 90°, or simultaneous bends in two dimensions are also available.

An illustrated catalogue with complete specifications on waveguide bends and other new millimeter-wave components is available from the manufacturer.

Bendix Appoints Umstead and Connaughton

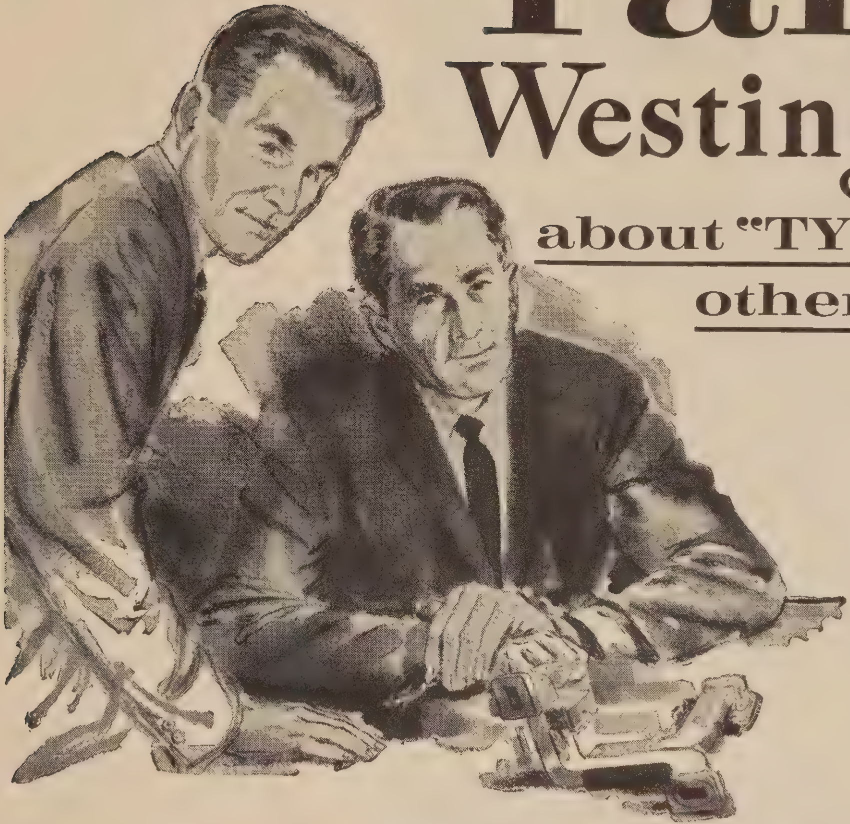
Red Bank Division of the Bendix Aviation Corp. has recently appointed Dwight L. Umstead, Jr., and William Connaughton, Jr. as Sales Engineers for the Electron Tube Products department. Umstead will be working out of the West Coast office at 117 East Providencia Ave., Burbank, Calif., telephone Victoria 9-3961, and will be servicing in conjunction with Eugene W. Swenarton the states of Washington, Oregon, Idaho, California, Nevada, Utah and Arizona.*i*

Connaughton will be temporarily working out of 17 Ruxton Road, Mattapan, Mass., telephone CU 6-1694, and will be covering the New England states of Maine, New Hampshire, Vermont, Massachusetts, Connecticut and Rhode Island. A permanent New England office address will be announced at a later date.

(Continued on page 164A)

Why don't you Talk with Westinghouse

about "TYPHON" and other Advanced Electronic Projects



The legendary Typhon, a dragon with 100 serpents' heads, has a modern counterpart in the Navy's newest weapons system project. The Typhon's long-range radar system is one of the continuing programs of advanced radar projects at Westinghouse-Baltimore.

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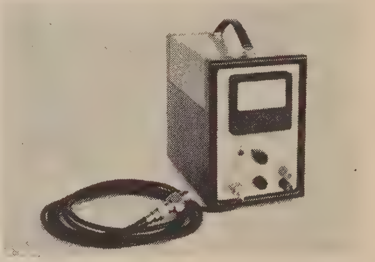
NEWS New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 162A)

Hydraulic Peak Pressure Gage

A new hydraulic Peak Pressure Gage that indicates peak pressures with full scale ranges of 0–4000 and 0–10,000 psi has been developed by **Hydel, Inc.,** 223 Crescent St., Waltham 54, Mass. This gage is designed for use by service, field and production personnel to troubleshoot and correct hydraulic systems that are subjected to excessive transient pressures. It is compact, sturdy and simple to operate and can be used by personnel unfamiliar with electronic equipment.



The instrument contains in one package a pressure pickup, an amplifier and a peak detector, followed by a large meter. The meter will indicate the true absolute peak of pressure transients as short as one millisecond in duration. In operation, the meter deflects rapidly to indicate the value of a pressure peak and then decays slowly to the steady state pressure of the system. As the meter is decaying any transient of a pressure level higher than the instantaneous meter reading will again cause the meter to deflect to the new peak.

For those instances where a visual presentation or a permanent record of the pressure wave is desired, the gage has an output terminal (AUX. OUT) on the front panel into which a standard oscilloscope or oscillograph can be attached. When used in this manner the Peak Pressure Gage becomes a pressure amplifier with a full scale (0–4000 or 0–10,000 psi) output of 40 volts and a frequency response of 0–1000 cps.

Ionics Purchases Electron Arc

Purchase of all assets of **Electron Arc, Inc.,** Lynn, Mass., was announced by Edwin R. Gilliland, president of **Ionics, Inc.** Manufacture and sale of a broad line of specialized electrical power supplies and equipment including transformers, rectifiers and control panels will continue under the new name Electron Arc Division, Ionics, Inc.

Also marketed are high intensity "point" light sources used for visual aids in guiding aircraft to safe landings and for a variety of other industrial and commercial applications.

Special electronic controls developed by Electron Arc permit transmission of voice communications between line-of-sight points using a pencil-thin beam of light which eliminates breaking radio security and reliance on slower visual code signals in military operations. Civilian applications may include communications where maximum privacy and security are needed and wires are not available, or in hazardous locations where radio waves could cause explosions or interference.

Present production facilities of the new division in Lynn will be utilized until Ionics' new plant on Rt. 128 in Waltham, Mass. is completed next year. The company recently announced acquisition of land for the plant, with site development to begin this spring.

Ohlsen Appointed by Rutherford

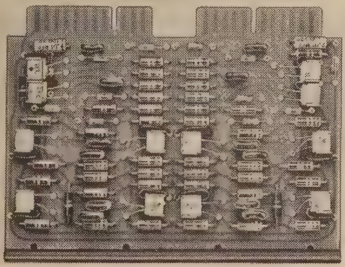
Rutherford Electronics Co., Culver City, Calif., announces the appointment of Richard J. Polsen as its production manager.

Ohlsen's responsibilities include; production, scheduling, manufacturing and quality control. Prior to joining Rutherford, Ohlsen was production manager of Networks Electronics Corp., Van Nuys, Calif. Previously he served 3 years with Coleman Engineering and 8 years with Universal Engineering Company as production manager.

A native son of Los Angeles, Richard J. Ohlsen resides at 2635 Corinth Ave., West Los Angeles, with his wife and son.

Synchronizer For Random Input

Computer Control Co., 983 Concord St., Framingham, Mass., has a new Model SY-101 Synchronizer, the latest addition to its line of digital computer modules, Series M, 3C-PACs.



The SY-101 is a double M-PAC designed either to synchronize random inputs to a clock, or to receive random parallel inputs and to deliver these serially to a counter. Each SY-101 package contains two identical synchronizer circuits. Up to six SY-101 packages may be grouped to allow accumulation of signals from 12 asynchronous sources for delivery to a single counter. Maximum synchronizing rate for an individual circuit is 30 kc, for a group of "n" circuits 30 kc/n.

Auxiliary circuits available for use with the SY-101 are the OM-102 clock source, and the BD-101 decade counter and several other M-PACs. Power requirements

(Continued on page 166A)

An Invitation

for

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and

ENGINEERS

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(Continued from page 165A)

per package: +20 volts dc ±10 per cent at 35 milliamperes, −90 volts dc ±10 percent at 1 milliampere. Unit price is $77.00, available from stock.

For further information contact J. I. Leabman, Marketing Manager, Eastern Division.

New Electronics Firm

A new company has recently been formed and chartered to manufacture computer components of high reliability for the electronic control of machinery and processes. **Embree Electronics Corp.,** headed by John M. Embree, a management staff engineer, has entered the expanded field of automation. Shortly, the firm expects to market a line of related products in the field of electronic analog computers. Embree Electronics is engaged in the research, design, and manufacture of its computers which are used to solve mathematical equations to predict the behavior of dynamic systems and to furnish data for successful operation of automatic reactor controls, submarine maneuvering controls, missile guidance systems and controls for industrial and chemical processes. Marketing and applications engineering will be done on a nationwide basis through the West Hartford, Conn. office and through electronics manufacturers representatives.

Waveguide Data Chart

A new "Standard Waveguide Data Chart," has been prepared by the **Narda Microwave Corp.,** 118-160 Herricks Rd., Mineola, L. I., N. Y. Featuring military as well as EIA designation numbers, the chart shows virtually all required electrical as well as mechanical parameters for all waveguides in use today.

Up to now, engineers have frequently had to devote considerable amounts of time to calculating certain characteristics, attenuation factors, power ratings, etc. The new chart provides the most commonly-used data, eliminating the necessity for calculations. Some of the parameters covered are: cut-off frequency, theoretical attenuation for both brass and aluminum waveguides, theoretical C W power rating and the waveguide wavelength from the lowest to the highest frequency in any given band.

Mechanical dimensions are also given for all waveguides, along with their tolerances. This is especially valuable, since these figures can be used as a guide to minimum tolerances throughout the rest of a system under design. Engineers who do not work with microwaves on a regular basis will also be able to use this chart to find radius dimensions, type of flange available—either cover or choke—in both aluminum and brass; as well as dimensional information to help them determine

(Continued on page 168A)

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On
The
Moon...

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Already Ryan is the world leader in continuous wave doppler navigation systems. This is one of several important reasons why Ryan is now the largest electronics firm in San Diego – *and the fastest growing!* If you are an electronics engineer ambitious to help advance the art, as well as your own career, through vital "frontier work" – we want you *right now* here at Ryan Electronics.

Ryan Electronics employs over 2000 people and has over one-third of the company's $149-million backlog of business. Under the leadership of some of America's most prominent scientists and engineers, Ryan is probing beyond the known . . . seeking solutions to vital problems of space navigation.

Expanding facilities of Ryan Electronics at San Diego and Torrance in Southern California are among the most modern in the West. You enjoy living that's envied everywhere, plus facilities for advanced study. Send your resume or write for brochure today: Ryan Electronics, Dept. 4, 5650 Kearny Mesa Road, San Diego 11, Calif.

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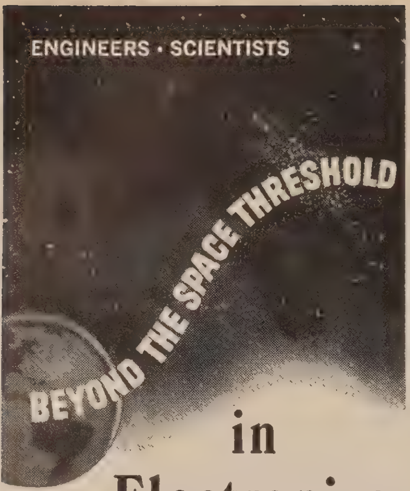

in
Electronics

New in approach—new in concept—Republic Aviation's space electronics programs are fostering the creation of unique, highly-specialized electronic systems for spacecraft, missiles and advanced aircraft. Leading the way in this important progress is the *individual contributor*—the man whose fresh perspective illuminates problems that defy conventional thinking. Aiding him to prove the validity of his vital new concepts are the extensive experimental facilities of Republic's recently completed $14,000,000 Research & Development Center.

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NEWS New Products

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(Continued from page 166A)

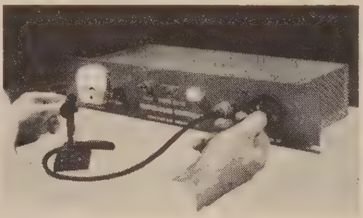
frequency ranges consistent with the mechanical and dimensional requirements of the equipment with which they are working.

Finally, the Narda designation number for each waveguide is also indicated, along with the EIA and military numbers, to facilitate ordering.

Copies of Narda's Standard Waveguide Data Chart may be obtained free from any of the company's representatives, or by writing directly to the firm.

Miniature Black Body Source

A new miniature infrared source for calibrating the seeking head of infrared guided missiles and other infrared sensitive elements in the 200°C to 600°C temperature range, has been introduced by the **Perkin-Elmer Corp.,** Norwalk, Conn. The new black body source, called the Model PE 521-6 Miniature Infrared Source, provides an accurately adjustable source of infrared radiation when used with the Model PE 521-6 Temperature Controller.



The infrared source and temperature controller can be used as a secondary standard of radiant energy by comparison with a primary source, or by auxiliary temperature measurement of the conical radiating cavity. The two units form a closed loop servo system which senses the temperature of the radiating core by means of a platinum resistance thermometer. The servo system also maintains the selected temperature by proportional electronic control.

The radiating element of the unit is a pure heated silver core with a conically shaped cavity. The high thermal conductivity of silver assures uniform temperature along the cavity walls. The surface of the cone is coated with a refractory material to increase its emissivity to near unity. A hole in the rear of the heated silver core allows access for convenient monitoring of the thermocouple.

The miniature infrared source and the temperature controller, constructed as separate units, are attached by means of a two-foot cable. A twenty-five foot extension cord is provided for remote operation. The source measures three inches long by three and one-half inches high. The temperature controller is housed in an 11-inch ×8-inch ×90-inch drawn aluminum cabinet.

Dryden V.P. of Pearce-Simpson

Pearce-Simpson, Inc., 3950 N.W., 28th St., Miami, Fla., Miami electronics manufacturer, announces the appointment of Robert E. Dryden as Vice President, Engineering. Dryden, a veteran in the electronics field, will head the new Research and Development Division of Pearce-Simpson.

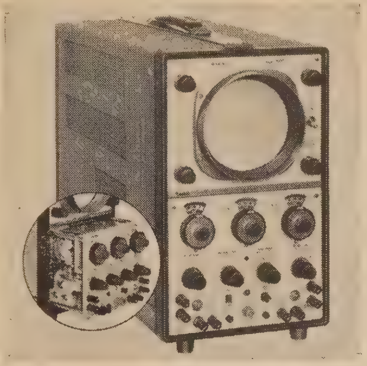
Dryden, a graduate of the University of Florida with a B.E.E. degree, formerly was director of the instrumentation division of Radiation, Inc., Orlando. Under Dryden's direction, Pearce-Simpson will establish a complete Research and Development division devoted to the field of military and commercial electronic test equipment. The new division will compliment the recently announced line of test equipment which Pearce-Simpson will manufacture under license agreement with Republic Aviation Corporation. The division will headquarter in the plant of the Pearce-Simpson Molded Plastics Div.

New Plant for Lieco

Lieco, Inc., Industrial Park, Syosset, L. I., N. Y., recently consolidated its operations in its new 20,000 sq. ft. plant at Syosset and announced the completion of arrangements with E.M.T. Corp., Newton, N. J. to market their new Balanced-Phase Flexible Waveguide. In making this announcement, Abe Zeitz, president of the company also stated that this makes it possible to supply his firms' customers with a complete line of waveguide assemblies in all frequency bands. These flexible waveguide lines supplement the variety of standard and custom rigid waveguide assemblies the firm is now producing.

Null-Readout Oscilloscope

A null balance technique, said to be used for the first time in an oscilloscope, introduces new standards of accuracy and speed for measuring analog data directly from the screen of the new Type 1100/700 Oscilloscope, a product of **Analab Instrument Corp.,** 30 Canfield Rd., Cedar Grove, N. J. To avoid the usual reading errors from the cathode-ray tube screen, the Analab Null-Readout System incorporates an anti-parallax scale, equivalent to a mirror-backed scale on a meter. With the Type 700 Dual-Channel Plug-In, incorporating 1% Null-Readout potentiometers for measuring amplitude on the two signal channels as well as sweep time, the Null Readout System is the fastest method for making direct, repeatable, accurate measurements without interpolation.



The Type 1100/700 Oscilloscope is of special modular design. The Type 1100 Main Frame is a basic, self-operable cathode-ray tube indicator which serves as the fundamental building block for the complete system of oscilloscopes. The Type 700 is a Dual-Channel Plug-In that is first of a series of plug-ins planned to operate with the Type 1100 Main Frame. This is the most flexible modular design yet conceived. There are 64 contacts available for the transfer of signals and voltages between the Type 1100 Main Frame and the plug-in.

In the Type 1100, operating without the plug-in preamplifiers, the X and Y post amplifiers have a bandwidth of dc to 500 kc with a sensitivity of 40 mv/cm (10 cm of full-scale undistorted deflection). When used with the Type 700, the over-all sensitivity of both signal channels is 100 μv/cm with a bandwidth of dc to 150 kc. The calibrated amplifiers can be used with single-ended or balanced input and provide deflection ranges from 1 mv full scale to 200 volts full scale (500 volts full scale uncalibrated) with a 17-step range switch in a 1, 2, 5 sequence for each amplifier. The 150 kc bandwidth is maintained on all ranges. The signal on either channel may be plotted against sweep time or against the other channel for X-Y plots.

The calibrated sweep offers speeds from 0.2 μsec/cm to 50 seconds full scale in 22 range steps, with 5:1 calibrated sweep expansion available on all ranges. Uncalibrated sweep times extend to 2 minutes.

The variable length sweep constitutes another innovation in oscilloscopes. It proves a gate signal with a variable length that is calibrated from 1 μsec to 50 seconds. Uncalibrated, the gate length can be increased to 2 minutes. The fall time of the variable-length gate can be used as a delaying trigger to delay the sweep of another oscilloscope or a second sweep in another plug-in soon to be made available. The variable-length gate can also be used to start and stop an external electronic counter for digital readout of sweep time, or to assist the counter in picking out portions of extremely difficult-to-synchronize complex waveforms.

(Continued on page 170A)

The widely varied capabilities of Space Electronics Corporation, a vital, expanding organization, have contributed to significant and practical developments for the nation's missile and space programs. An interesting roster of projects, largely derived from the firm's own creative ideas, offers challenging career opportunities. A typical concept pioneered by the company has led to a detailed plan for relaying television or telephone signals between continents, by means of.....

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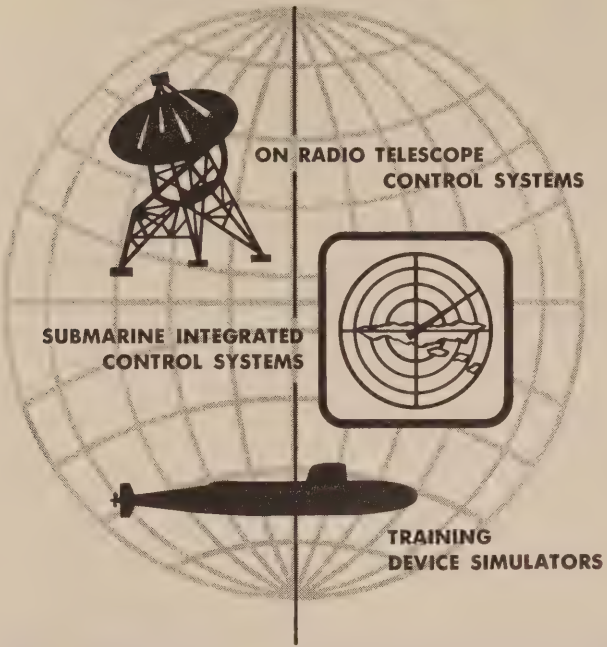

IN SYSTEMS APPLICATION
SECTION

Pioneer in design and development of nuclear powered, missile firing submarines, Electric Boat Division of General Dynamics is expanding its successful and diversified research and development activities in advanced technological areas: large control systems (world's largest wind tunnel, precise radio telescope); training equipment (simulators and trainers for missiles, submarines and other weapons systems); submarine integrated control systems (to include ship and weapons control, display, sensor, communications and data processing systems).

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ELECTRICAL ENGINEERS
To perform system analysis for determination of servo requirements, particularly for large horsepower applications; and to design special purpose electronic circuits for use in control, computation, measurement and communications area.

SYSTEMS EVALUATION ENGINEERS
To perform conceptual engineering and production engineering of electronic equipment, with particular regard to circuit development.

If you are qualified in any of these areas, and would like to live and work on the Connecticut shore just half way between New York and Boston, send a resume with salary requirements to James P. O'Brien, Technical Employment Supervisor. All inquiries in confidence.

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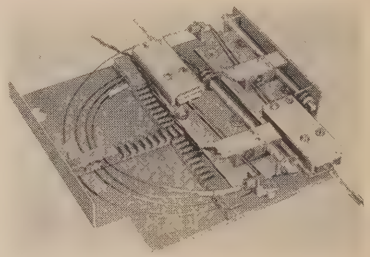
(Continued from page 169A)

Ultrasconic Delay Line

The Ultrasonic Delay Line, U.D. Series developed by **Curtiss-Wright Corp.,** 35 Market St., East Paterson, N. J., launches and propagates accoustic waves along a wire transmission media of low temperature coefficient of delay to achieve delay stability over a wide range of temperature (5 parts per million per degree centigrade over a range of −55°C to 100°C). The relatively low speed of wave travel which is characterized by the torsional mode has a wide range of delay, 5 to 12,000 microseconds. The unit is incased in a small, rugged and compact enclosure.

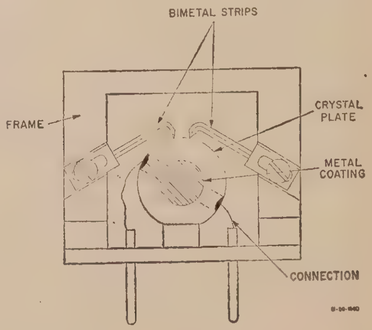


The simple and rugged construction of the coiled wire delay media permits the unit to withstand a wide range of environmental military vibration and shock. The U. S. Series has a center frequency ranging from 100 kc to 1.2 mc with a maximum bandwidth of 1 mc. The unit can be used with a carrier frequency or without for pulsed operation. It also has a wide range of input and output impedances to allow for optimum impedance matching.

The U.D. Series is available in both standard and custom designs to most applications for computer bit storage, coders and decoders, telemetering and navigational systems, radar simulators, missiles and aircraft.

Crystal Stabilizer

More precise control of radio frequencies can be achieved with a newly developed and fairly simple stabilization device for quartz crystals, the **Department of the Army** announced.



The new device promises real savings in size, weight and power requirements over the special electronic ovens or heaters which are now widely used in maintaining constant crystal temperature.

The device was developed at the **U. S. Army Signal Research and Development Laboratory,** Fort Monmouth, N. J., by Dr. Eduard A. Gerber of West Long Branch, N. J., one of this country's foremost authorities on frequency control.

The new device uses temperature-sensitive bimetal strips, or fingers, pressing against certain spots on the edge of the crystal. Each of the strips is made of two metals with different rates of expansion and contraction. Acting much like thermostats used in heating systems, these metal fingers apply the right amount of pressure to keep the crystal operating on frequency as temperature fluctuates. The fingers may number one, two, or more, depending on the application.

In spite of the high degree of stability in crystals, temperature variations do tend to cause a change in the crystal vibration frequency—or "frequency drift." While crystal ovens have proved satisfactory for reducing drift in many applications, the typical oven may occupy two cubic inches or more of critical space and also consumes a considerable amount of power in maintaining constant crystal temperature.

By contrast, the new device can be made one-tenth the size of the crystal oven, being entirely mechanical in operation, and cuts power requirements. In battery powered equipment, including satellite systems, space and weight reductions are significant, especially considering the possibility of reducing battery size and weight due to decreased power requirements.

Another benefit which may be gained from use of the bimetal strips is extended useful life of crystals. The heat of the ovens causes accelerated aging of crystals.

Radial Connector

Elco Corp., M St. Below Erie, Philadelphia 24, Pa., announces a new Radial Connector, designed in co-operation with one of Elco's customers. The connector has 15 contacts at approximately 5° spacing; guide pins and bushings; set-screw looking device which permanently secures connector in mated position. Connector employs Varicon mating principle; contacts are from Elco Series 5000. The forklike Varicon contacts, with 4 mating coined surfaces,

(Continued on page 172A)

A
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Unique systems programs underway at the Defense Systems Department embody the engineering disciplines listed above. If you can contribute in *any* of these areas, you'll have an opportunity to learn as many of the *others* as your abilities permit. Here's how it works:

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STEP 2 Learn one, two, three or more of the other disciplines applying to this system and broaden your overall systems knowledge.

STEP 3 Move up to higher levels of responsibility in true systems engineering as fast as your growing capabilities permit.

STEP 4 Based on your interests and aptitudes, you have the opportunity to build further from systems engineering into program management.

TAKE THIS STEP NOW! Get the full facts on how you can take advantage of this plan to gain abilities and responsibilities in large scale systems engineering. Drop a note outlining your education, experience and interests, in professional confidence, to:
Mr. E. A. Smith, Box 6-F

DSD DEFENSE SYSTEMS DEPARTMENT
A Department of the Defense Electronics Division

GENERAL ELECTRIC

Northern Lights Office Building, Syracuse, New York

DESIGN ENGINEERS

check these openings in advanced gyro and electrical components design

In 1949, Honeywell developed and flight tested the floated gyro for control systems. Since then, its Gyro Design Group has become the focal point for a multi-million dollar component development program, supporting the inertial navigation industry. This is, perhaps, the most advanced program of its kind. It has expanded rapidly and now has openings for additional top level engineers.

This group is involved in all fields of gyro design. It works in such areas as *precision gyro and accelerometer design, hydro-dynamic bearings, vibratory mechanisms, precision electric suspension techniques and gyro magnetics.*

The men needed to fill these positions should be capable of developing advanced concepts for gyros and of following through on their projects. They should have a minimum of two years' (and up to twenty years') experience in such areas as *precision gyro mechanics, servo techniques, digital data handling, electronics packaging, advanced instrumentation,* or *magnetic component design.*

To discuss these or other openings, write Mr. James A. Burg, Dept. 662D, Aeronautical Division, 1433 Stinson Blvd., Minneapolis 13, Minn.

Honeywell

H *Military Products Group*

To explore professional opportunities in other Honeywell operations coast to coast, send your application in confidence to H. K. Eckstrom, Minneapolis 8, Minnesota.

NEWS New Products

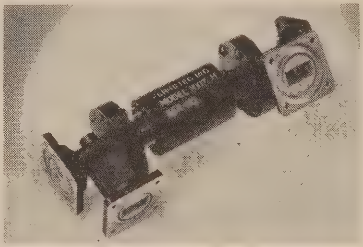
These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 171A)

assure low contact resistance, high current rating, complete reliability after thousands and thousands of insertions and withdrawals. Varicon mating principle described in Elco Catalog V3; Technical Bulletin 108A gives all data and specifications relating to Series 5000 board-to-board printed circuit Varicons.

Ku-Band Switch

Highlight of **Ferrotec Inc.'s**, Newton Mass., IRE Show booth display was the introduction of a new Ku-band high power fast switch enabling two microwave antennae to be time-shared by a common transmitter and receiver, maintaining high isolation between the magnetron and load.



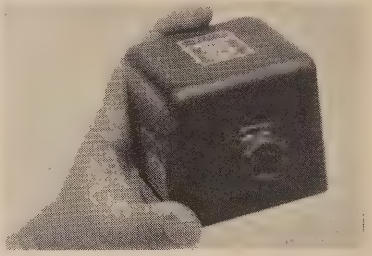
The Model R-107H is said to be the first fast-switch capable of handling peak power levels of 100 kw, at 100 watts average, and can be switched at speeds under 10 microseconds. Switching is performed using less than 70 watts peak and 2 watts average power.

The switch operates over a 2% band between 15.7 and 16.9 mc., with loss of 0.5 db, maximum VSWR of 1.20, and isolation between ports greater than 20 db. The switch is operable over the fulll temperature range between −40°C and +100°C.

Ferrotec's high power fast-switch employs the Faraday rotation principle, using a ferrite structure between a pair of compact two-mode transducers. The output transducer is oriented 45° with respect to the input transducer.

Among additional applications of the Model R-107H are service as a high frequency, high-power modulator, and as a variable attenuator.

DC/DC Power Supplies



Arnoux Corp., 11924 W. Washington Blvd., Los Angeles 66, Calif., designers

MANAGER OF MATHEMATIC MODELING

BELL AVIONICS DIVISION
has immediate opening
at Tucson, Arizona Facility

Ph.D. (or equivalent) in E.E. or Physics. A minimum of ten years experience required in communications and propagation. Responsibility will include the direction of a group of engineers in the modeling of electromagnetic interference as related to the modern army.

Send resume in confidence to

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DIRECTOR OF ENGINEERING
BELL AIRCRAFT CORPORATION
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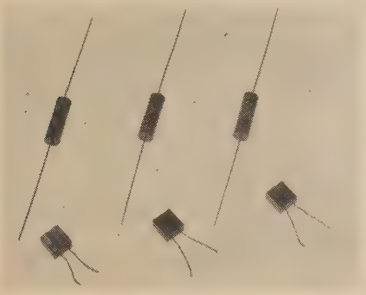
Hamilton, Ohio, to the attention of Kenneth L. Faist, Assistant Personnel Director, General Personnel Administration.

and manufacturers of telemetry and instrumentation products, announced this week the production of a new line of dc/dc power supplies. This new line, primarily for missile and other airborne applications, is designed to step up dc power and for precision regulation against line and load variation, even under large, ambient temperature changes and other severe environmental conditions. Meets MIL-E-5272C. These solid-state units provide maximum reliability, minimal size, and a range of voltages from 5 vdc to 250 vdc in 34 standard models.

For further information, write to Tom Watson at the firm.

Chokes Solve RF Noise Problems

The Magnetic Products Div. of **Stanwyck Winding Co., Inc.,** P.O. Box 70, Newburgh, N. Y., announces two types of encapsulated chokes containing Ferroxcube ferrite shielding beads and having large values of RF reactance and resistance in HF and VHF regions for broadband isolation and decoupling. The tubular type utilizes coaxial leads; the transistor module type has both leads projecting from one side. Both have an inherently high impedance and low Q characteristics which make them ideally suited for radar and microwave IF strips, parasitic suppression in parallel tube amplifiers, tube life test racks, radio interference suppression from spark plugs, relay contacts, etc. They are color coded for ease of identification, meet MIL standards and are available in bulk for manual insertion or in tape-type reels for automatic machine insertion in printed circuit cards. Write for technical bulletin—or, if you wish, order an engineering kit containing 20 chokes in various values for $10.



Welch Sales Mgr. of Relay Sales

Richard O. Welch has been appointed sales manager of **Relay Sales,** West Chicago, Ill., announced E. E. Rullman, president of the national relay distributor. Welch, formerly with Automatic Electric Co., has over 23 years background of engineering, manufacturing, field application and sales of all types of relays. For the past 12 years Welch worked exclusively on application engineering of relays, switches, and custom assembly in all electronic markets and in the telephone industry.

(Continued on page 174A)

FACTS and FIGURES about SANDERS That Add Up to TOP ENGINEERING OPPORTUNITIES

1 Dramatic growth in 8 years from an 11 to 1300-man organization.

2 Diversity—20 R&D contracts at time of writing.

3 Stability—substantial production activities as well as advanced R&D.

4 Backlog at beginning of '60—$20,000,000.

5 Gross sales of $10,600,000 in 1959—an increase of 18% over 1958.

6 A sales goal of $15,000,000 in 1960 (with very reasonable expectations of meeting it).

7 A record of original engineering achievements such as PANAR® radar; FLEXPRINT® flexible printed circuits; TRI-PLATE® microwave products.

8 Location: Nashua, a progressive city of 50,000, is in the beautiful New Hampshire hill country less than an hour from downtown Boston. No state income or sales taxes.

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Through Project Engineer level. Need not be specialists, but must have creative abilities and backgrounds of VHF transmitters and receivers, communications systems in general, data processing techniques, propagation and must be capable of translating this knowledge into complex integrated systems.

RECEIVER DESIGN ENGINEERS

VHF electronically scanned airborne receivers, filters, problems in spurious response reduction and multiplexing.

CIRCUIT DESIGN ENGINEERS

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Openings exist for Senior, Project and Junior Engineers. Junior Engineers need have no experience beyond their baccalaureate in E.E. or Physics.

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Mr. Thomas A. Fike
960 Industrial Road
San Carlos, California
LYtell 1-8411

LITTON INDUSTRIES
Electron Tube Division
San Carlos, California

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

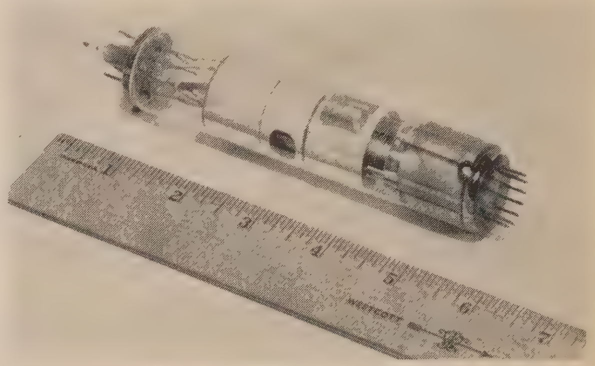
(Continued from page 173A)

High Frequency Radar Amplifier

An improvement in receiver sensitivity of a coherent Moving Target Indicator radar system, equivalent to a 50% increase in range or a five-fold boost in transmitted power, is claimed by a new high frequency amplifier tube used in combination with a "synchronous pumping" mode of operation.

Other fields of application include long range radar for air traffic control and surveillance, early warning of hostile aircraft or missiles, and satellite surveillance.

The new equipment was developed by **Zenith Radio Corp.,** 6001 Dickens Ave., Chicago 39, Ill. and tested at the Rome Air Development Center, Griffiss Air Force Base, New York. Application of the synchronous pumping technique was originally suggested by Kenneth G. Eakin of RADC.



L-BAND QUADRUPOLE AMPLIFIER TUBE

The electron beam parametric amplifier was recently developed by a team of research scientists headed by Dr. Robert Adler, associate director of research at Zenith, in association with Dr. Glen Wade, Stanford Electronics Laboratory. The device is regarded as a "promising newcomer to the vacuum tube family," and provides high signal amplification over a broad frequency band with extreme stability and very low noise, the announcement states.

Tests of the equipment at RADC, the announcement states confirmed expectations that the synchronous pumping technique permits full utilization of the amplifier's low-noise potentialities in high-performance, moving target indicator radar. Prior to the tests, the announcement explained, a general, but erroneous, belief existed among scientists that some measure of impairment of the performance of parametric amplifiers, caused by noise picked up by the idler channel and "dumped" into the signal channel of the tube, could be avoided.

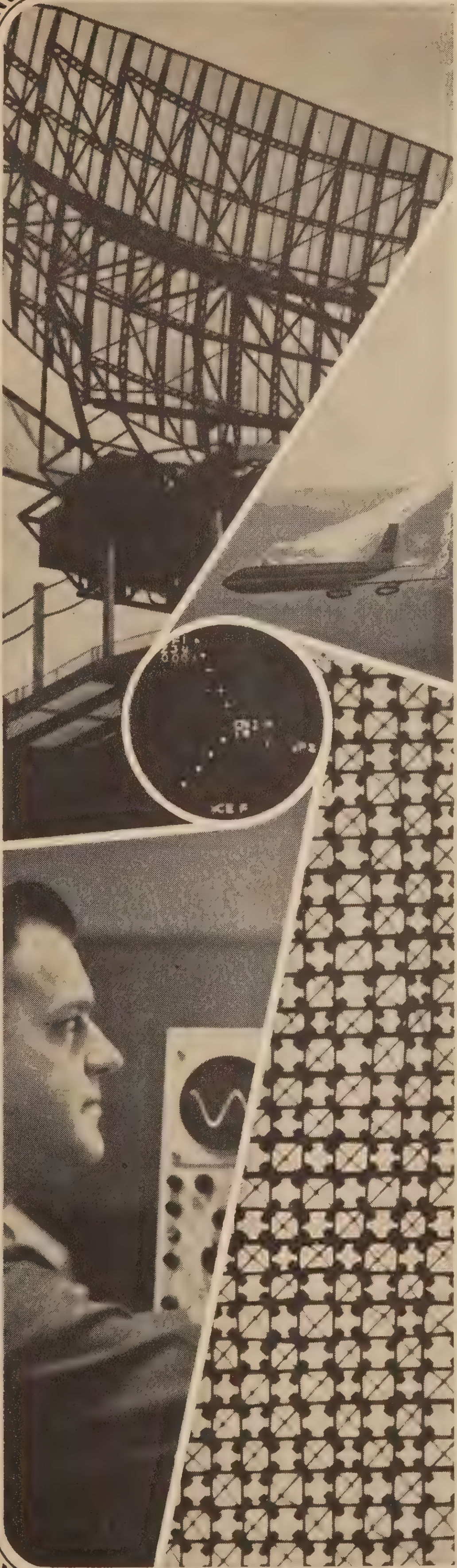
During the tests, minimum detectable signal measurements were performed on the radar, with observations taken on the dipolar and unipolar video output of the MTI synchronous detector, and also the video output of the normal linear detector. With synchronous pumping, the average improvement in sensitivity observed was 10 db on the synchronous-detector channel, and 9 db on the linear-detector channel.

The announcement stated that these figures exceed the expected 7 db improvement, probably because the effective antena temperature was less than 290°K.

Comparison photographs of the A-scope display of output of the synchronous and linear detectors, with "non-synchronous" and also with synchronous pumping, were made. In each case, the IF gain was adjusted to equalize the noise levels. In the condition labelled "non-synchronous pumping," an independent signal generator replaced the synchronous-pump generator.

The improvement with synchronous pumping over non-synchronous pumping is clearly evident in the photographs, the announcement said.

(Continued on page 176A)



ENGINEERS • SCIENTISTS

AIR TRAFFIC CONTROL SYSTEM DEVELOPMENT

. . . A growing area of activity at The MITRE Corporation where original thinking can find broad application

The MITRE Corporation is directing its experience in System Engineering toward the development of an integrated air defense/air traffic control system. To test the techniques and designs for full-scale system implementation, an advanced active experimental program, SATIN (SAGE Air Traffic Integration), is being developed by MITRE under contract from the Federal Aviation Agency. Employing a SAGE AN/FSQ-7 computer and associated radar and communications networks maintained by MITRE, SATIN will be capable of controlling aircraft in a test area that includes New England, New York and New Jersey.

MITRE's Air Traffic Control Department faces exacting problems in the areas of system design, development and evaluation. Precise methods must be developed for providing improved en route air traffic control services without compromising the air defense mission.

Engineers and scientists with an interest or previous experience in air traffic control problems are invited to investigate immediate Technical Staff openings.

Inquiries may be directed in confidence to:
VICE PRESIDENT — TECHNICAL OPERATIONS

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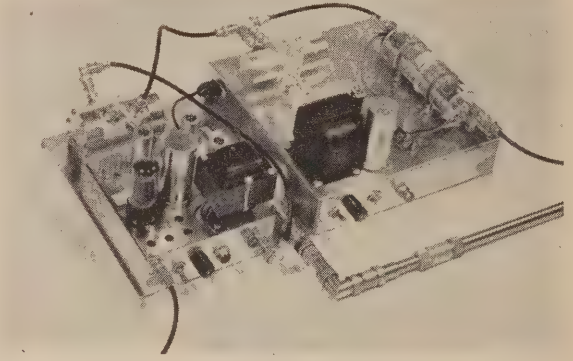
These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 174A)

The quadrupole amplifier tube employed in the tests was inserted directly between duplexer and mixer of the existing radar. Since the Adler tube is unidirectional, no circulator or isolator is needed. Its input and output impedances are resistive and independent of gain. The existing impedance match is not disturbed, therefore, nor is the stability of the receiving system impaired.

The frequency response of the amplifier used is flat over a band of about 80 mc centered at 1300 mc. It is normally operated at about 20 db gain, although the gain may be adjusted from −1 db to over +30 db by varying the pump power. (With the pump off, the tube acts as an isolator, with about 1 db insertion loss.)


SYNCHRONOUS PUMP GENERATOR

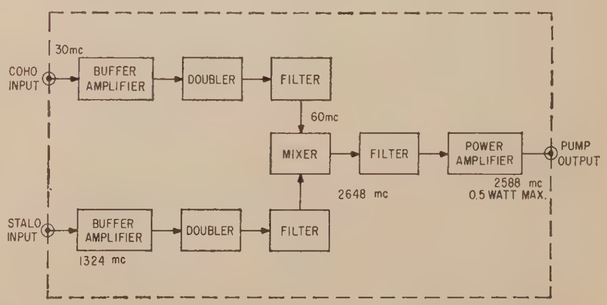
The shape of the bandpass characteristic is completely independent of gain. Gain stability is high, with only about a 1.3 db change in gain (at 20 db gain) occurring for a 10% change in pump power.

The broadband noise figure of the amplifier tube itself, the announcement said, is 1.3 db. Prior to insertion of the amplifier, the radar system noise figure was 8.5 db. With the amplifier in place, the resulting system noise figure was 1.6 db. This is the single channel noise figure, the announcement stated, since no allowance for "idler-channel" effects has to be made when the synchronous pumping technique is employed in the system.

The particular tube used in the tests at RADC was developed by R. L. Cohoon, research engineer in Dr. Adler's group at Zenith.

In a coherent MTI radar system using the new amplifier and the synchronous pumping technique, the announcement stated, it is possible to derive a synchronous signal for pumping the parametric amplifier and use it in such a way that the signal and idler are made to coincide exactly.

Under these conditions, signal and idler add coherently in the detector and cooperate in producing the output. Since the coherence applies to noise inputs and to the desired echoes alike, no reduction in signal-to-noise ratio results from the presence of the idler channel.



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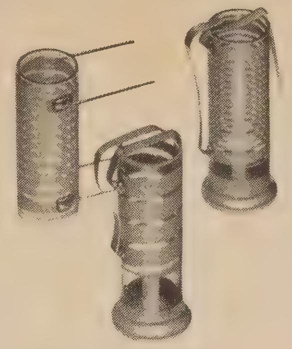
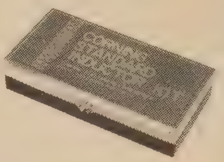
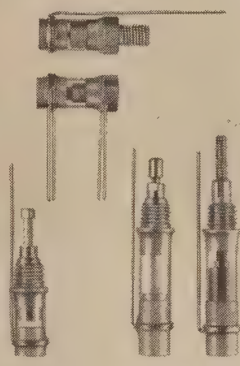
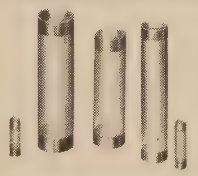
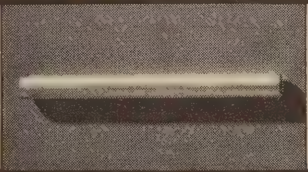
CORNING STANDARD INDUCTORS		**DELIVERED OFF THE SHELF** 27 values ranging from 0.05 uh to 2.0 uh. High Q, 120 to 250. Frequency range from 10 MC to over 250 MC. High reliability under shock and vibration, since conductor is fired into glass, cannot shift. Low TC: 0 to +20 ppm/°C. Operation range from −55°C. to +125°C. No drift even under drastic dT. For panel or printed board mounting. Standard tolerance is ±10%. ±5% also available above 0.25 uh. **NEW KIT** for prototype work contains 10 different inductors with four tuning cores and other accessories, along with 50-page brochure of performance charts. Contact distributor serviced by Erie Distributor Division. 
CORNING TRIMMER CAPACITORS		**ROTARY** in three models for high-frequency tuned circuits. Standard: to 12.0 mmfd; Split bushing: to 12.0 mmfd; Precision: to 4.0 mmfd; Full rating from −55 to +125°C., TC: +50 ±50ppm°C. Nonporous silver plating for corrosion resistance available on request. **DIRECT TRAVERSE** for linear tuning. Full rating from −55°C. to +125°C. TC: +50 ±50 ppm/°C.; 0.5 to 3.0 mmfd; 1.0 to 7.5 mmfd; 1.0 to 8.0 mmfd; 1.0 to 12.0 mmfd. **MINIATURES** for ultrafine tuning. .40 uuf△/turn. Fixed cavity tuning. Silver-plated hardware for highest Q and corrosion resistance. Zero derating at 125°C. No backlash. Complete circumference thread contact with direct traverse motion. Panel mount or printed board. 1 to 4 mmfd; 1 to 8 mmfd; 1 to 12 mmfd; 1 to 18 mmfd.
CORNING ENCLOSURE TUBES		Both rectifier tubes and bushings. Made from selected glass for maximum mechanical and thermal strength. High temperature operation. High metallized bond strength: 1200 to 1500 psi. Impervious to moisture, fungi, dust, etc. Transparent, so you can inspect inserts visually. Also available with frosted glass. Made to your specifications.
DELAY-LINE COIL FORMS		For distributed constant delay lines on low loss forms. Scribe gap: 0.0040″ ±0.0010″ wide. O.D.: 0.200; 0.230; 0.240; 0.250. Up to 8″ lengths with up to 40 lines. Forms can be produced to your specs. Short delivery time.

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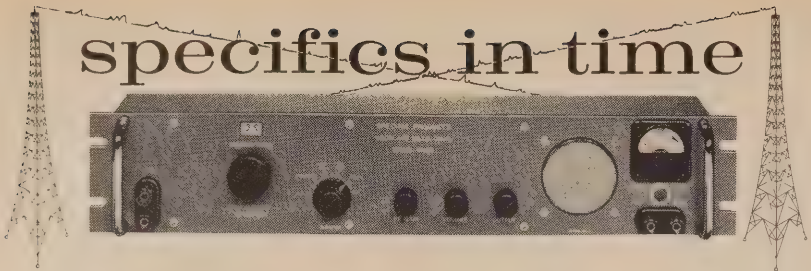

specifics in time

If you are being pressed for ever increasing accuracies in the dimension of time, **Specific Products** and the National Bureau of Standards can help.

NBS radio stations WWV and WWVH provide pulsed time signals accurate to at least one part in fifty million. By tuning one or more of the station frequencies you can make use of these exquisitely accurate time tics.

The new, all transistorized Model WVTR receiver by **Specific Products** enables you to do just that. This rack mount version of our previously announced Model WWVT (portable) brings to your calibration lab every bit of that one-in-fifty-million-parts accuracy. Furthermore, its convenience of operation makes a cinch of otherwise tedious calibration work.

Model WVTR rack mount

Five National Bureau of Standards frequencies — 2.5, 5, 10, 15, 20 and 25 mc — are instantly available at the touch of the dial. The conveniently packaged unit measures 3½" x 19". Power is either by 6 size D flashlight batteries or AC power pack. Both a speaker and an S meter are provided for frequency comparison and signal level. Price of Model WVTR is $725.

As a public service **Specific Products** presently publishes two bulletins on how you can use WWV and WWVH broadcast signals in your work. Bulletin #159A generally describes the free broadcast service. Bulletin #460 specifically describes the use of the broadcasts in calibration work.

Send for complete literature

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These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 176A)

For this reason, the announcement continued, performance attained is fully characterized by the so-called broadband noise figure of the parametric amplifier, which can be extremely low.

The pumping signal is generated by doubling the stalo (1324 mc) and coho (30 mc) signals that are available from the existing radar, and mixing the two resulting frequencies. An amplifier and filter select the difference (2588 mc), which is precisely twice the transmitter frequency (1294 mc), and apply it through a phase shifter to the quadrupole pumping structure.

With a linear detector, the pump phase is of no importance, but an optimum phase exists when the MTI is employed.

The improvement in sensitivity observed applies not only to the MTI channel employing the synchronous detector, but also to the normal channel with a linear detector. This results from the presence of both signal and idler components of the target echo within the pass band of the IF amplifier. Under these conditions, precise coherence is no longer necessary to obtain performance corresponding to the broadband noise figure; synchronization of the pumping source merely insures that the the idler channel will be accepted by the subsequent system.

The consequences of these results are that synchronously-pumped parametric amplifiers may be directly applicable to a much broader range of practical systems.

X-Y Oscilloscope

Type 503, a differential-input X-Y oscilloscope with sensitivity of 1 mv/cm, in the dc-to-450 kc range has been designed by **Tektronix, Inc.**, P.O. Box 831, Portland 7, Oregon. It utilizes a minimum number of tubes (equivalent 17 plus rectifiers) for the maximum degree of reliability.

Vertical and horizontal amplifiers are identical. Characteristics include: input

(Continued on page 182A)

Day by day the Polaris missile gets nearer to its first submarine test firing... nearer the day when, operational, it will become one of our nation's most formidable deterrents to aggression. For with submarines serving as mobile missile launching pads, any target on earth is within deadly striking range if retaliation becomes necessary.

The Polaris-launching submarines are splendidly fitted out not only to aim and fire and accurately guide the missile, but also to defend themselves. Advanced Sperry submarine equipment contributes to both these functions. For precise navigation there is SINS (Ship's Inertial Navigation System), automatic steering and stabilization, depth detectors, gyrocompasses, diving and maneuvering controls, instrumentation, and computers... and the NAVDAC computer which correlates all navigation data. For anti-submarine warfare the subs have Sperry torpedo fire control systems, sonar sub detection equipment, the attack periscope itself. At two special laboratories both aspects of the Polaris program are being refined and integrated: one of which simulates submarine navigation, the other the environments of the sea.

Sperry's role in the Polaris program is typical of the Company today, achieving through specialized divisions an integrated capability that is contributing to every major arena of our environment. General offices: Great Neck, N. Y.

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50 YEARS 1910 1960

Armed Forces Standardize Microfilm

Engineering Data Micro-reproduction System Covers Films, Punch Cards, Aperture Cards

The Armed Forces, operating active files containing more than 50 million drawings, have set military requirements for microfilming engineering drawings and related data.

The standards and specifications released April 15, 1960, by the Department of Defense for its Engineering Data Micro-reproduction System establish uniform methods for microfilming and standard formats for data presentation.

These uniform methods and standard formats, the Defense Department said, offer great space, time, and money savings.

New possibilities for inter-service exchange of engineering data are opened through the use of microfilmed drawings and related data, the Department of Defense announced.

What does this mean to industry?

Military agencies using the specifications of the Engineering Data Micro-reproduction System will ask contractors to submit engineering data in 35mm roll microfilm and punch cards. From the microfilm and punch cards, such military agencies make aperture cards to distribute engineering data for the procurement, maintenance, and supply of the nation's weapons systems.

In addition, other military agencies may require contractors to submit completed aperture cards. In these cases, the master microfilm and distribution copies are furnished in mounted aperture cards.

Even now, a number of prime contractors and sub-contractors are using a portion of the newly-adopted specifications and standards. For them, the new requirements will be integrated into existing programs.

Many contractors, anticipating the standards and specifications, have held microfilm programs in abeyance. Their engineering departments now have a ready-made set of instructions for upcoming programs.

The new standards and specifications are expected to have a cumulative effect. As more companies have microfilm equipment, industry will intensify its use of microfilm for distributing data. Even before specifications were announced, prime and sub-contractors were exchanging engineering data in microfilm format.

Industry helped set standards

Compatibility with industry is the keystone in the new standards and specifications of the Department of Defense. Industry originates much of the engineering data used by the DOD. Industry, in helping to set requirements, has created instructions that can be used for its own operations.

Standards cover broad areas

The standards and specifications documents already released are:

MIL-M-9868, Microfilming of Engineering Documents, 35mm Requirements for;

MIL-P-9879, Photographing of Construction/Architectural Drawings, Maps and Related Documents, 105mm, requirements for;

MIL-C-9877, Cards, Aperture;

MIL-C-9878 Cards, Tabulating and Aperture for Engineering Data Micro-reproduction System;

MIL-STD 804, Formats and Coding of Tabulating and Aperture Cards for Engineering Data Microreproduction System;

MS-21319, Gage, Aperture Cards No. 201-1.

Interim Federal Specifications cover silver halide, diazo-type, and heat developing microfilm.

The complete Department of Defense standards and specifications cover:

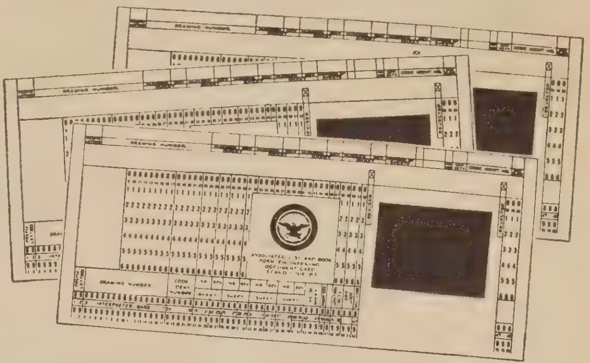
- The raw film stock used in microfilm;
- The methods and techniques of microfilming engineering data for the Armed Forces;
- The formats of the tabulating cards used to generate aperture cards;
- The formats of the aperture cards used as carriers for the microfilm data;
- The methods and techniques of mounting microfilm into aperture cards;
- The wide range of equipment to be used in the micro-reproduction system. This equipment includes microfilm cameras, testing equipment to inspect filmed engineering data, film mounters, film printers, and print-out units.

3M makes microfilm so easy to use

You can depend on 3M's continuing research, precision manufacturing, and standards-compatible products to make microfilm so easy to use.

FILMSORT Aperture Cards and Copy Cards, long used by Government and industry, are designed to meet the specifications and standards for the Engineering Data Micro-reproduction System. And now, to speed your use of FILMSORT Aperture Cards, 3M supplies both the printed card and the aperture. You save in shipping costs. You get your cards faster.

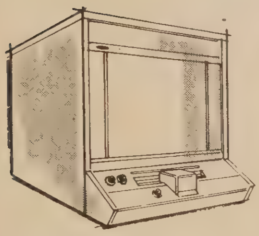
FILMSORT Microfilm Copiers, Mounters, and Readers are designed exclusively for Filmsort Aperture Cards. They are engineered to make your micro-reproduction system profitable.



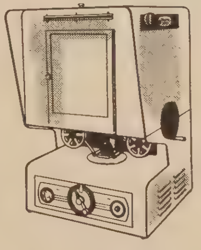
THERMO-FAX "Filmac 200" Reader-Printers make microfilm practical for industry and Government. The advantages of a reader and a printer are combined in one compact, low cost unit. Huge viewing screen . . . simple push-button operation . . . you can obtain copy after copy in 18″ x 24″ size, or half size prints, of engineering drawings and records from microfilm in FILMSORT Aperture Cards. The "Filmac 100" Reader-Printer delivers 8½″ x 11″ copies in seconds.

For more information about the new Defense Department microfilm specifications and how they affect your business, mail the coupon right away.

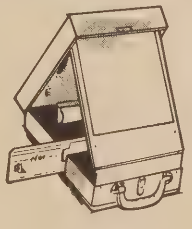
Modern Microfilm Products from 3M



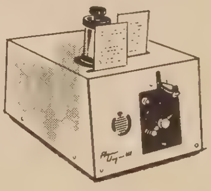
THERMO-FAX
"Filmac 200" Reader-Printer



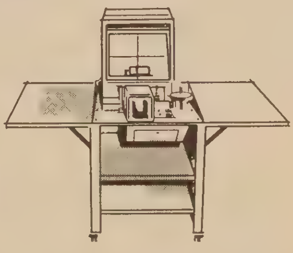
THERMO-FAX
"Filmac 100" Reader-Printer



FILMSORT
"Inspector 50" Reader



FILMSORT
"Uniprinter" Copier



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NEWS New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 178A)

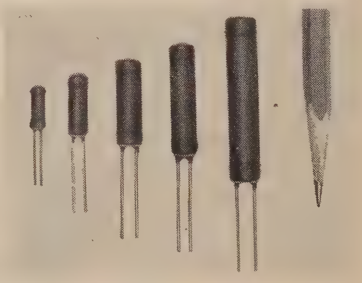
stages electronically regulated, calibrated steps to 20 v/cm, adjustable between 14 steps and to over 50 v/cm uncalibrated, differential input and constant input impedance (for easy probe use) at all sensitivities.

Other features include: functional panel layout, 8×10 cm viewing area, 21 calibrated sweep rates with 5 degrees of magnification, electronically-regulated power supplies, and extremely adaptable trigger facilities.

The price is $625. The rack-mounting model, RM503, is available now at $640.

Base Mounted Wire Wound Resistors

Type PRS wire wound, miniature, precision resistors produced by **Dale Products Inc.,** Columbus, Neb., are base mounted with two parallel leads. They need an area equal to their circumference for mounting purposes. These new resistors, designed to meet power requirements in printed circuits where space is at a premium, offer a solution to miniaturization design problems.



These new resistors are available in 4 wattages, 3, 5, 7 and 10, and in 5 sizes ranging from $\frac{9}{16}\times\frac{3}{16}$ to $1\frac{25}{32}\times\frac{3}{8}$. Tolerance range is 0.05, 0.1, 0.25, 0.5, 1 and 3%. Resistance range is from 0.05 ohm to 175K ohms.

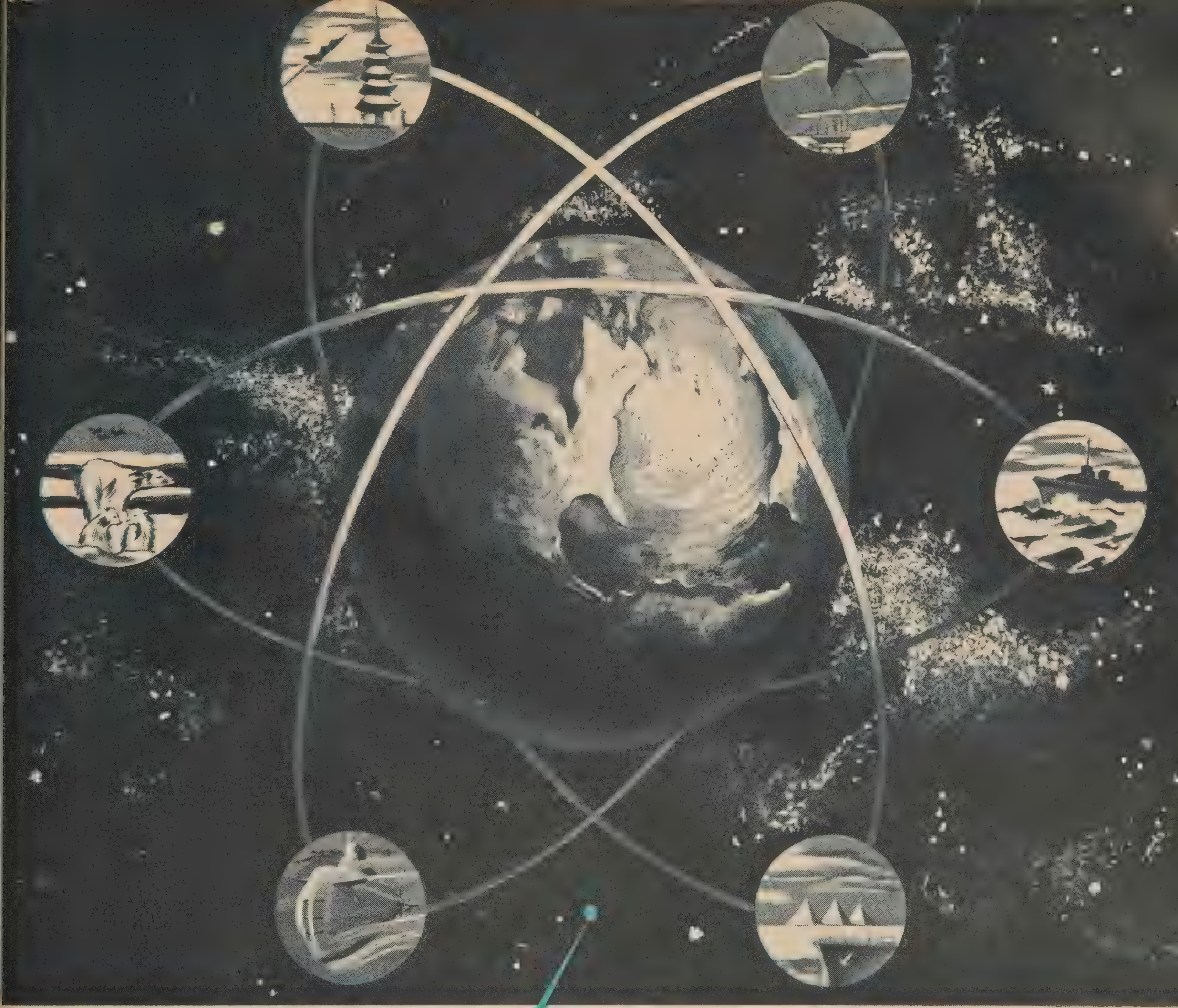
PRS-2 provides 100% power up to 100°C and derates to 0 at 275°C. The other four sizes provide 100% power to 25°C and derate to 0 at 275°C.

For complete information write for PRS bulletin from the firm.

Power Meter

The FXR Model B832T transistorized temperature compensated power meter is a compactly packaged instrument which will accurately measure either CW or pulsed RF power in five full scale direct reading ranges from 30 micro watts to 3 milliwatts. This is a product of **FXR, Inc.,** formerly F-R Machine Works, Inc., 26-

(Continued on page 184A)



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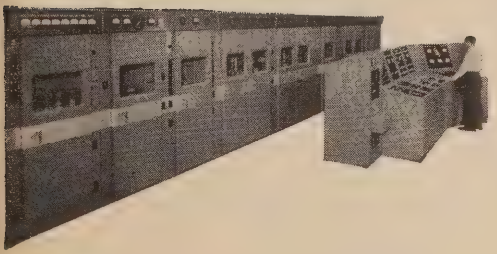

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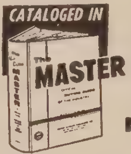

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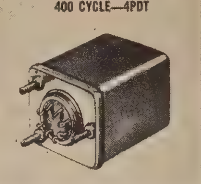
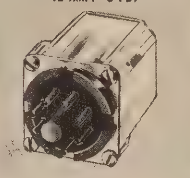
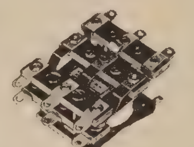


SERIES 26D—DUST COVER 10 AMP.—3 PDT



SERIES 26—MEDIUM POWER 20 AMP.—3 PDT



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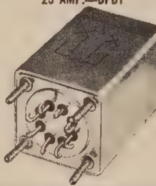
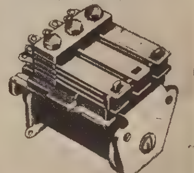
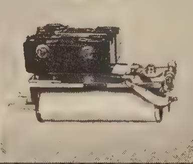


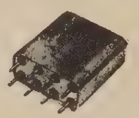
SERIES M—MINIATURE TELEPHONE 3 AMP.—4 PDT



SERIES AS—SNAP ACTION TELEPHONE



SERIES KX—MICRO-MINIATURE*



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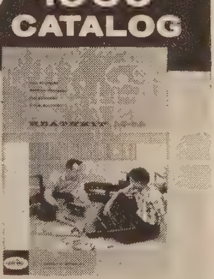

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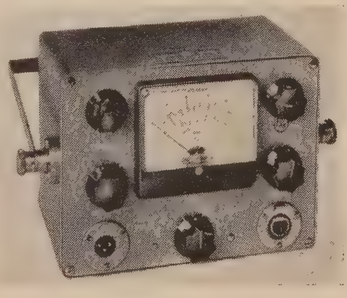
NEWS New Products

(Continued from page 182A)

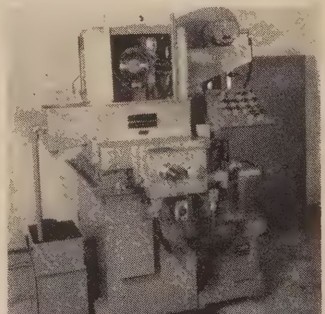
12 Borough Pl., Woodside 77, N. Y. Values can be read in MW or DBM. The instrument incorporates a unique method of controlling the accuracy and stability of RF power measurements. Readings are virtually drift free; compensation of ambient temperatures makes the instrument a hundred times more stable than comparable measuring devices, even inthe 30 microwatt range. Provision is made to calibrate the dc voltage at all levels and the bridge is self-balancing at 200 ohms. Range switching without recalibration is another advantage.



The meter is energized by a self contained rechargeable nickel cadmium battery. The charging circuit operates from a 105 to 125 volt ac, 50 to 400 cps source. The use to charge ratio is 2 to 1.

Crystal Wafer Slicer

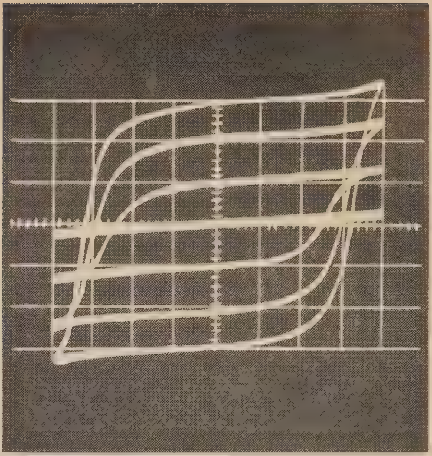
An automatic backoff mechanism is used in an automatic semiconductor crystal slicing machine recently developed by **Fitchburg Engineering Corp.,** Fitchburg, Mass. The backoff prevents imperfections in the crystal surface.



After the spindle makes the plunge cut, the hydraulic cylinder backs the entire work support (including the indexing mechanism) 0.01 inch away from the wheel. The spindle can then be raised without marking the crystal. The cylinder also takes out blacklash in the indexing mechanism while the cut is being made.

Spindle speed is controlled up to 9,200 rpm by a Variac. Cutting wheel downspeed is regulated by a flow control valve which can be locked after adjustment. An oversized precision spindle is used to reduce diamond wheel wear. The machine's

(Continued on page 186A)



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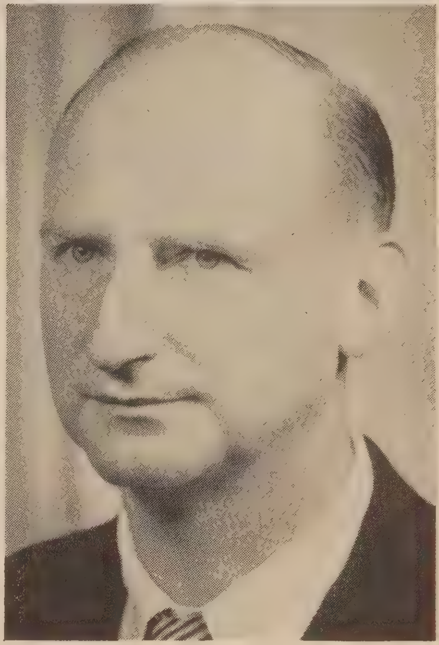

1960's *Morris Liebmann Memorial Prize* goes to J. A. Rajchman, of RCA Laboratories, for helping develop magnetic devices to process information. IRE is proud to honor Mr. Rajchman, and to salute all who, in this challenging decade of the '60s, work for the advancement of the radio art and apply it to the betterment of our lives.

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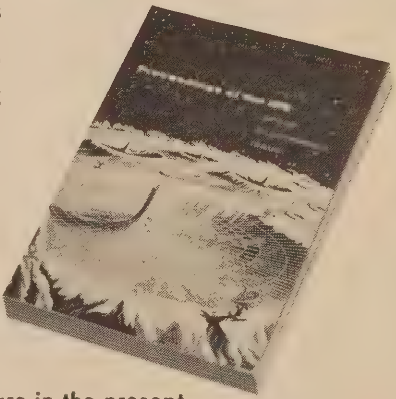

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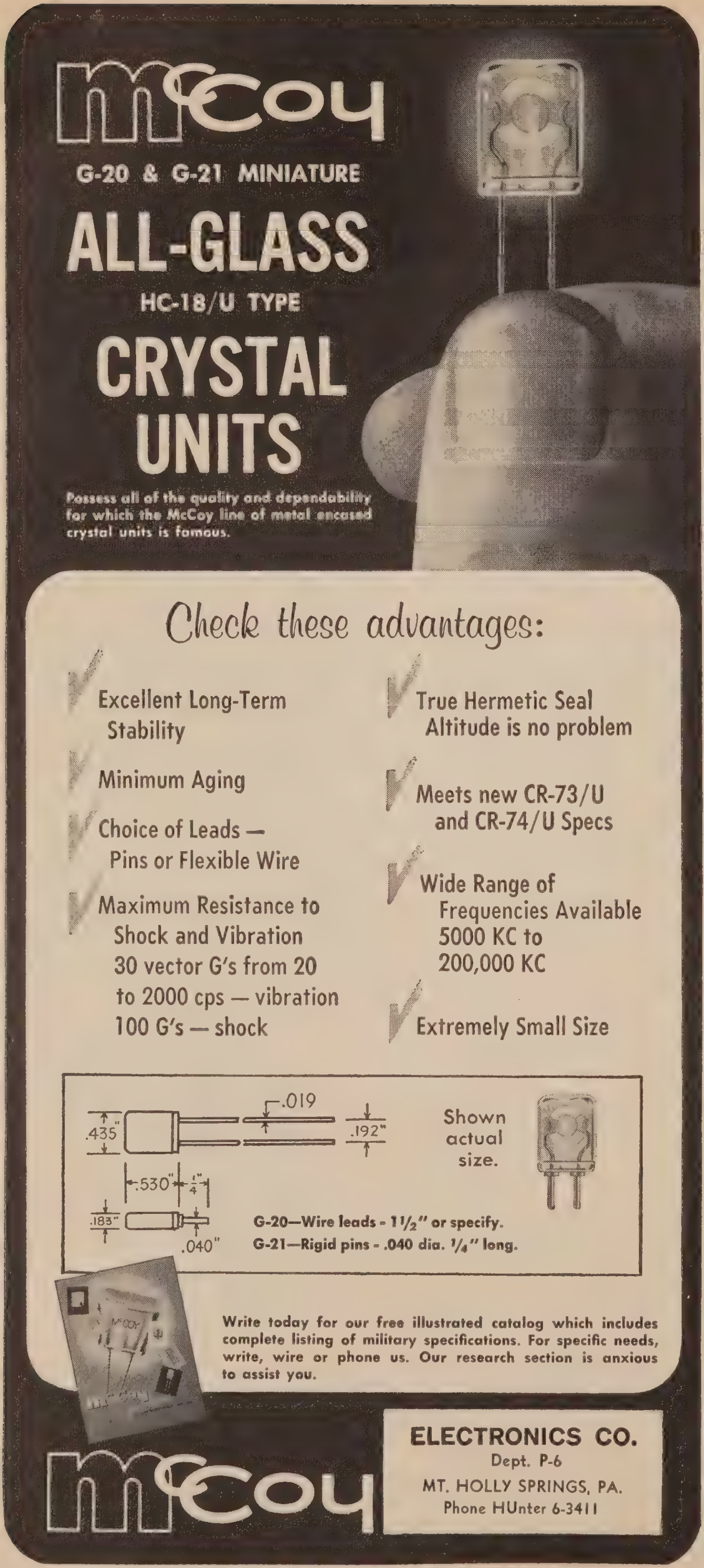

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NEWS New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 184A)

weight, 2800 pounds, helps prevent vibration.

The machine is being used by Sylvania Electric Products, Inc., Woburn, Mass. Cutting performance reported by Jack Robertson, supervisor of germanium preparation, is: wafer thickness can be adjusted from 0.025 to 0.007 inch, ±0.0005 inch. Wafers are uniform and do not break.

Two wafers may be sliced at a time from ingots up to 4 inches long. The ingots are oriented and mounted on a steel plate with adhesive. Diamond wheels from 0.01 to 0.020 inch thick are used. The coolant is water mixed with a water-soluble oil. Continuous coolant flow is provided by a constant displacement pump.

Lafferty Chief Engineer of Boonton Electronics

Boonton Electronics Corp., 738 Speedwell Ave., Morris Plains, N. J., has announced the appointment of Raymond E. Lafferty as chief engineer. Lafferty will be concerned with the design and development of new test equipment and with application engineering. He has had over 20 years of engineering experience in broadcasting and component and instrument design, and has most recently been with the Daven Company as Assistant chief engineer.

Filter Brochure

"Infratron Interference Filters" is the title of a new 4-page brochure just issued by **Infrared Industries, Inc.,** P.O. Box 42, Waltham 54, Mass.

Important performance characteristics and other unique features are described on four basic types of infrared interference filters: *Long-Pass; Short-Pass; Band-Pass;* and *Spike.*

Also described are the company's capabilities in providing highly specialized coating services for general and very specific applications.

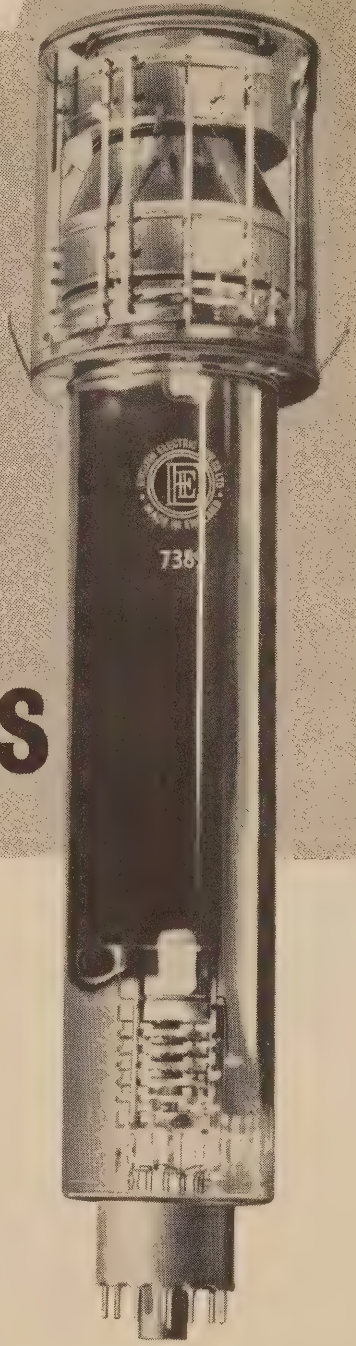
This literature is available. Please write to the firm.

Panel Meter

General Electric Co's., Schenectady 5, N. Y., line of "Big Look" ac and dc panel meters has been augmented by the addition of a new 4½ inch model.

(Continued on page 188A)

4½" IMAGE ORTHICONS



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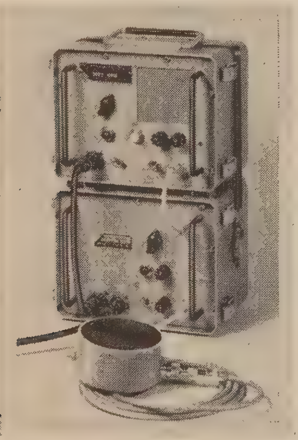
C.E.C. offers resistive attenuators that cover an entire waveguide band. These attenuators maintain a flat attenuation charactertistic over their entire waveguide band. ATTENUATION: 3 db, 10 db or 20 db are offered as Standard. Other attenuation values can be preset to your specifications.

INSTRUMENTS



VHF-UHF FREQUENCY CALIBRATOR MODEL 121

Range: 50 mc to 11,000 mc in crystal controlled steps of 50 or 100 mc.

Output Level: In excess of —70 dbm minimum for all markers.

Accuracy: ±0.005% at any frequency, unaffected by temperature or power input variations.

HARMONIC MULTIPLIER AMPLIFIER ADAPTER

Output Waveform: CW or Pulse.

Output Level: increases amplitude to —30 dbm in frequency range from 1,000 to 11,200 mc with marker spacing of 1,600 mc. Lower amplitude (—60 dbm) markers are generated with a spacing of 400 mc

BROADBAND ANTENNA

Designed for use with the Harmonic Adapter, this broadband antenna covers the entire range from 1,000 mc through 11,200 mc

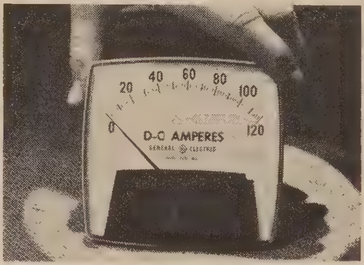
Used in combination, the three units provide a fast go-no go, remote calibration check on aircraft radar receivers, without the need for connecting cables to the aircraft.

CONTROL ELECTRONICS CO., INC.
Ten Stepar Place, Huntington Station, N.Y.

NEWS New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 186A)



According to engineers at the company's instrument department, West Lynn, Mass., the new 4½ inch instrument incorporates the same appearance and ease of readability presently available in smaller "Big Look" panel meters. It can be supplied with custom made scales to comply with customers' appearance design or color-coding requirements.

Method of mounting is standard, conforming to the ASA C39.1 (1955) specification for 4½ inch panel meters.

The instrument will be priced competitively, and will be available from company and nation-wide distributor stocks by May 1, 1960.

Semiconductor And Microwave Devices Catalogs

Three new short-form catalogs describing **Microwave Associates, Inc.'s** products are now avilable.

For convenience the short-form catalogs cover separately (specifications, photos) the products of Microwave Associates three divisions:

Semiconductor Products manufactures Microwave Silicon Diodes, Varactors, and Computer Diodes.

Microwave Components Division manufactures Waveguide Components, Test Equipment, and Custom Engineered Microwave assemblies.

Microwave Tubes and Devices manufactures Duplexer Tubes, Magnetrons, Ferrite Devices, Coaxial Limiters, Switches, and Complete Duplexers.

Write to Department AH, Microwave Associates, South Ave., Burlington, Mass. for your copies.

Dielectric Test Bridge Literature

A four-page, two-color bulletin presents detailed information on a dielectric test bridge developed by **Rohde & Schwarz,** West Germany. It is available from **Rohde & Schwarz Sales Co. (U.S.A.), Inc.,** 111 Lexington Ave., Passaic, N. J.

Designated Type VKB, the bridge measures dissipation factors and capaci-

(Continued on page 190A)

tubes and semi-conductors.

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world's largest tube and transistor specialist. Special purpose, Transmitting, Receiving. All important brands. Name the type, name the brand, name the quantity—we have it. Famous nation-wide service—fast delivery anywhere. *Get your free subscription to the E.T.S. Bulletins* for authoritative, up-to-date new-item and new-availability news—write on your company letterhead today.

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- **Hermetically sealed transformer designed to MIL-T-27A**
- **Remote sensing and DC vernier**

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DC OUTPUT:

(Regulated for line and load)

MODEL	VOLTAGE RANGE[1]	CURRENT RANGE[2]	PRICE
LA50-03A	0-34 VDC	0- 5A	$395
LA50-03AM	0-34 VDC	0- 5A	$425
LA100-03A	0-34 VDC	0-10A	$510
LA100-03AM	0-34 VDC	0-10A	$540

[1] The output voltage for each model is completely covered in four steps by selector switches plus vernier control and is obtained by summation of voltage steps and continuously variable DC vernier as follows:

MODEL — VOLTAGE STEPS

LA 50-03A, LA 50-03AM—2, 4, 8, 16 and 0-4 volt vernier
LA100-03A, LA100-03AM—2, 4, 8, 16 and 0-4 volt vernier

[2] Current rating applies over entire output voltage range

Regulation: Line: Better than 0.15 per cent or 20 millivolts (whichever is greater).
Load: Better than 0.15 per cent or 20 millivolts (whichever is greater).

Transient Response: Line or Load: Output voltage is constant within regulation specifications for step function line voltage change from 100-130 VAC or 130-100 VAC or for step-function load change from 0 to full load or full load to 0 within 50 microseconds after application.

Ripple and Noise: Less than 1 millivolt rms with either terminal grounded.

AC INPUT:

100-130 VAC, 60 ± 0.3 cycle. This frequency band amply covers standard commercial power lines in the United States and Canada.

OVERLOAD PROTECTION:

Electrical: Magnetic circuit breaker front panel mounted. Special transistor circuitry provides independent protection against transistor complement overload. Fuses provide internal failure protection. Unit cannot be injured by short circuit or overload.

REMOTE SENSING:

Provision is made for remote sensing to minimize effect of power output leads on DC regulation, output impedance and transient response.

PHYSICAL DATA:

Size: LA 50-03A. . .3½″ H x 19″ W x 14⅜″ D
LA100-03A. . .7″ H x 19″ W x 14⅜″ D

Panel Finish: Black ripple enamel (standard). Special finishes available to customers specifications at moderate surcharge. Quotation upon request.

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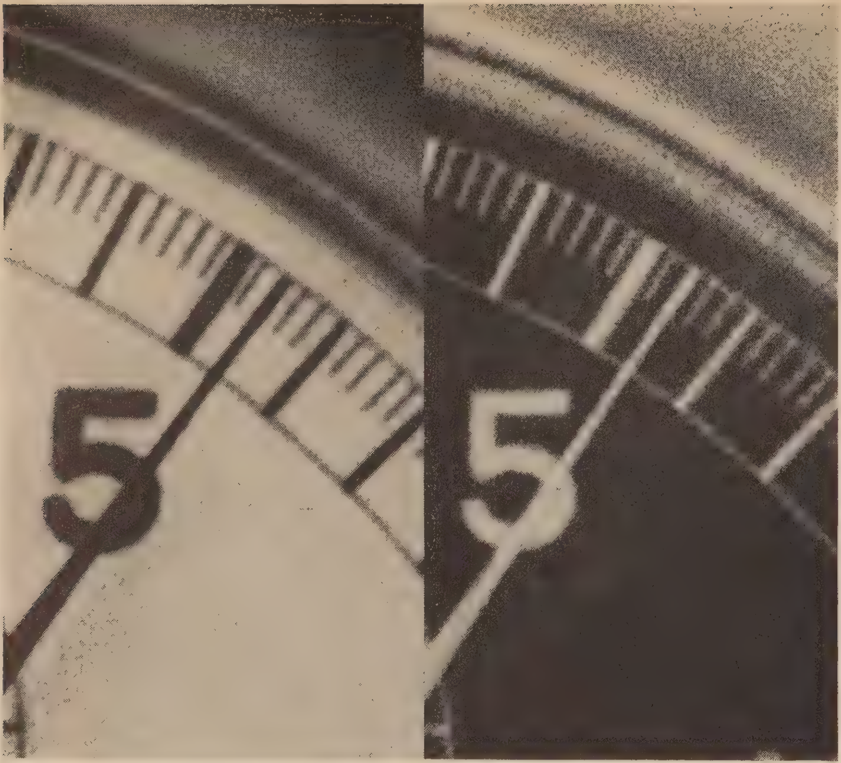
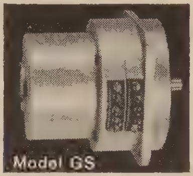
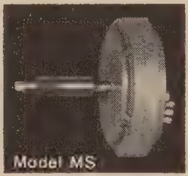


precise synchronization





±0.1 degree... no load to full load. Constant angular rotation is assured with Models GS and MS Synchronous motors. There's no "cogging" action to disturb precise synchronization. 60-pole rotor which reduces shaft speed without gearing helps provide an accuracy within 0.1 degree of angle under all load conditions.

Model GS. Incorporating an integral induction-start motor, the phonic-wheel-type GS can be operated from a vacuum tube amplifier on frequencies from 60 to 3600 cps. It may be operated single phase in the plate circuit of a single-ended amplifier or as a two-phase motor when driven by push-pull amplification. Motor current is app. 75 milliamperes per phase, output up to 1/100 hp.

Model MS. Offering big power for its small size, the MS is a phonic-wheel-type motor capable of operating on signal frequencies from 150 to 4000 cps. Power and starting characteristics on frequencies as low as 150 cps are excellent. It measures but 4"x1⅝", yet torque at 1800 rpm is as high as 6 inch ounces per phase.

Investigate the superior performance characteristics these advanced synchronous motors offer. They are a product of one of the world's leaders in the development and manufacture of facsimile and radio communications equipment.

Westrex Corporation

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(Continued from page 188A)

tances of any kind of capacitors between 10 $\mu\mu$f and 1 μf. It finds special application in the investigation of insulating materials, since it permits determination of the dielectric constant and the dissipation factor of solid or liquid specimens. The bridge is equipped with guard circuit for measurement of three and two terminal capacitors.

Of particular interest are the sample holders described in the bulletin which are available for measuring the dissipation factor of solid and liquid material and of the insulation of wire. There is also available an extension unit for determining large dissipation factors.

Accuracy of dissipation factor and capacitance measurements are discussed, ranging from ±4 to ±7% for the former and ±1 to 2±% for the latter.

Telemetal Names Kent

Jack H. Kent has been appointed general manager of **Telemetal Products, Inc.,** 75 N. 11 St., Brooklyn, N. Y., a subsidiary of Polarad Electronics Corporation. In his new capacity he will be responsible for the over-all operation of the Telemetal organization. Kent was formerly with Landau Metal Products, Inc. He has a wide background encompassing twenty years of experience both in engineering and manufacturing phases of the sheet metal industry.

Telemetal Products, Inc., founded in 1951, manufactures a wide variety of precision sheet metal assemblies for both industry and the military.

Transistorized RF Voltage Calibrator

Kay Electric Co., Dept. PI, 14 Maple Ave., Pine Brook, N. J., has announced the development of the Megavolter, a fully transistorized RF Voltage Calibrator for use in obtaining voltage calibrations of RF signal generators and vacuum tube voltmeters.

Megavolter
KAY ELECTRIC CO. PINE BROOK, N.J.

(Continued on page 192A)

NUMBER 5—RELIABILITY SERIES

Bourns Trimpot®
Puts the Proof in Humidity-Proof

Plunging a potentiometer into near-boiling water is just one of the ways Bourns puts the proof in humidity-proof. Every Trimpot unit made takes this 60-second bath with the water simmering at 90°C. Air expanded by the heat creates four pounds of pressure inside the potentiometer—enough to cause bubbles—if it leaks. Only if the unit is completely leak-free does it pass the test.

Bourns humidity proofing starts at the beginning—with original design and selection of materials. The plastic chosen for Trimpot cases, for example, displays the unusual properties of high insulation resistance and extremely low moisture absorption. Further protection against humidity results from manufacturing procedures, such as internal potting of the resistance element and sub-components. Finally, Bourns samples all production for compliance to MIL-STD-202A, Method 106 as a routine part of a Reliability Assurance Program. As a result, Trimpot does more than "resist" moisture; it keeps moisture out.

For more information about the industry's largest selection of humidity-proof adjustment potentiometers—wirewound and carbon in a variety of sizes, power ratings, operating temperatures, etc.—write for new Trimpot summary brochure and list of stocking distributors.

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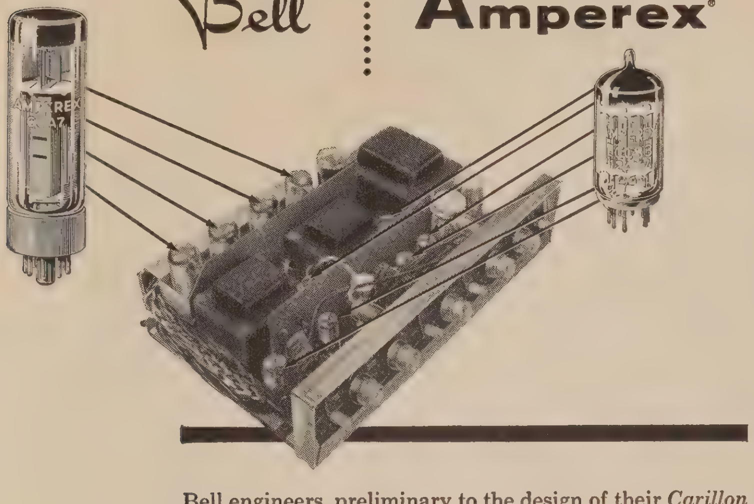
tubes by Amperex®



Bell engineers, preliminary to the design of their *Carillon Model 6060, 2 channel, 60 watt Stereo Amplifier,* canvassed the industry for tube types offering something truly exceptional in the way of reliability, low distortion, low noise, low hum and absence of microphonics.

As has frequently been their experience, the people at Bell found these qualities best exemplified by Amperex tubes. Thus, the tube complement of the Bell Model 6060 includes two Amperex 6CA7/EL34's and three Amperex 12AX7/ECC83's in each channel.

These and many other Amperex 'preferred' tube types have proven their reliability and unique design advantages in the world's finest audio components.

Applications engineering assistance and detailed data are always available to equipment manufacturers. Write: Amperex Electronic Corp., Special Purpose Tube Division, 230 Duffy Avenue, Hicksville, L. I., New York.

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7189: 20 w., push-pull
6BQ5/EL84: 17 w., push-pull
6CW5/EL86: 25 w., high current, low voltage
6BM8/ECL82: Triode-pentode, 8 w., push-pull

VOLTAGE AMPLIFIERS
6267/EF86: Pentode for pre-amps
12AT7/ECC81: } Twin triodes, low hum, noise and microphonics
12AU7/ECC82: }
12AX7/ECC83: }
6BL8/ECF80: High gain, triode-pentode, low hum, noise and microphonics

RF AMPLIFIERS
6ES8: Frame grid twin triode
6ER5: Frame grid shielded triode
6EH7/EF183: Frame grid pentode for IF, remote cut-off
6EJ7/EF184: Frame grid pentode for IF, sharp cut-off
6AQ8/ECC85: Dual triode for FM tuners
6DC8/EBF89: Duo-diode pentode

RECTIFIERS
6V4/EZ80: Indirectly heated, 90 mA
6CA4/EZ81: Indirectly heated, 150 mA
5AR4/GZ34: Indirectly heated, 250 mA

INDICATORS
6FG6/EM84: Bar pattern
IM3/DM70: Subminiature "exclamation" pattern

SEMICONDUCTORS
2N1517: RF transistor, 70 mc
2N1516: RF transistor, 70 mc
2N1515: RF transistor, 70 mc
IN542: Matched pair discriminator diodes
IN87A: AM detector diode, subminiature

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These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 190A)

The lightweight, compact Megavolter can be used right on the production line, without the aid of expensive and delicate external voltage standards, to obtain readings of 1% accuracy to 10 mc; 2% accuracy to 50 mc; 3% accuracy to 200 mc and measure from 1 millivolt to 1-volt rms from 1 kc to 200 mc.

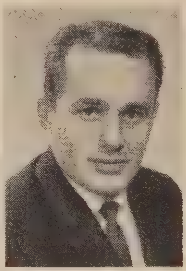
This instrument is a complete comparison measurement device, utilizing the principle that both 1-volt dc and 1-volt rms develop equal power (heating) in a given thermal element.

When used to calibrate voltage output of RF signal generators, the output voltage is read directly on the meter in error voltage percentage, as referenced to 1 volt. Full scale error voltage input of 0.0 to 1.1-volt rms can be read.

For calibrating RF VTVM's, precise voltages are available at panel terminals between 0.001 and 1-volt rms, referenced to 1-volt rms input. Several voltage points may be checked on each side of the VTVM being calibrated.

Acton Labs. Appoints Webber and Swanson

Acton Laboratories, Inc., subsdiary of Technology Instrument Corp. of Acton, Mass., announced the promotion of Donald W. Webber to western sales manager and Stanley C. Swanson to eastern sales manager.



D. W. Webber

S. C. Swanson

Webber has been Sales Engineer for Acton's Electronic Instruments and Communication Equipment in Los Angeles. His headquarters will be 1225 West Olympic Blvd., Los Angeles, and he will be responsible for sales in the West Coast and Rocky Mountain Area.

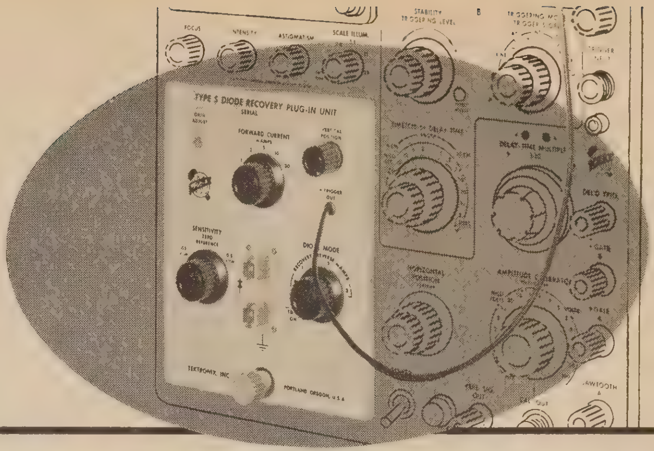
Swanson was formerly a Sales Engineer. He will now be responsible for sales in the Eastern part of the United States with headquarters in Acton, Mass.

Lambert Operations Manager of Electronic Controls

J. B. Lambert was appointed operations manager of **Electronic Controls Inc.,** 85 Magee Ave., Stamford, Conn. Lambert

(Continued on page 194A)

NEW SEMICONDUCTOR-DIODE Test Unit for measuring recovery characteristics



TEKTRONIX TYPE S PLUG-IN UNIT

You can now display semiconductor-diode switching characteristics on your Tektronix Plug-In Oscilloscope. With Tektronix Type 540-Series and Type 550-Series Oscilloscopes you can find:

Effective lifetimes to 2 nanoseconds
Stored charge to 10 picocoulombs
Junction capacitance to 2 picofarads
Base resistance to 0.25 ohm

The Type S Unit describes the diode in terms of its parameters, while most other currently employed methods describe the diode in terms of its performance in a particular circuit—not necessarily the one in which it will be used. With the Type S method you can predict the behavior of many diodes in many circuits, as well as compare diodes for performance in a particular circuit.

A Type S Unit, plugged into your Tektronix Oscilloscope, can save you many hours of experimentation. Call your Tektronix Field Engineer for a demonstration in your application.

MAIN CHARACTERISTICS

Calibrated Forward Currents
1, 2, 5, 10, and 20 milliamps.
Calibrated Reverse Currents
0, 0.1, 0.2, 0.5, 1, and 2 milliamps.
Diode Shunt Capacitance
9 picofarads.
Amplifier Sensitivity
0.05 v/cm and 0.5 v/cm, calibrated.

Type S Diode Recovery Unit **$250**
f.o.b. factory

Note: Risetime of the Type S Unit depends on the capabilities of the oscilloscope with which it is used, therefore the ability to analyze fast diodes with Tektronix Type 530-Series Oscilloscopes will be affected by the lower risetimes of these instruments.

Tektronix, Inc.

P. O. Box 500 • Beaverton, Oregon
Phone MItchell 4-0161 • TWX—BEAV 311 • Cable: TEKTRONIX

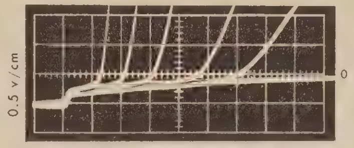


Fig. 1—Diode A

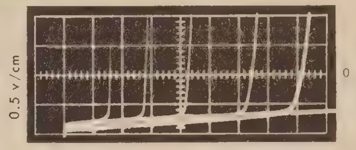


Fig. 2—Diode B

I forward—10 ma. I reverse—2, 1, 0.5, 0.2, 0.1, 0 ma.

Observation of the recovery curves of Figures 1 & 2 shows both reverse current and recombination accounting for removal of the stored charge. It is thus possible to determine not only the stored charge for any of the five forward currents available, but also the rate of recombination. With this information, it is possible to predict diode action to fast transients in any circuit.

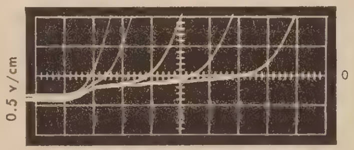


Fig. 3—Diode A

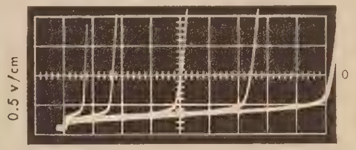


Fig. 4—Diode B

I forward—1, 2, 5, 10, 20 ma. I reverse—2 ma.

Observation of the recovery curves of Figures 3 & 4 shows that the amount of stored charge is proportional to forward current while the recovery time is so short that negligible recombination occurs. Under this condition, after the stored charge is cleared the reverse bias increase is limited only by the diode capacitance (and the shunt capacitance of the instrument). This rate of increase is easily measured at a particular reverse voltage, and thus, the diode capacitance at that voltage can also be determined.

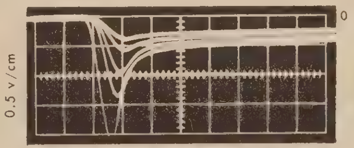


Fig. 5—Diode A

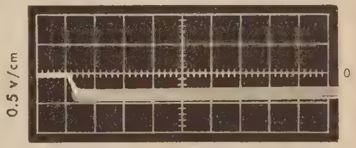


Fig. 6—Diode C

Turn-on—magnified. I forward—1, 2, 5, 10, 20 ma.

Observation of the turn-on characteristics of Figures 5 & 6 shows that the voltage drop across a diode suddenly switched on is not always initially as low as the steady-state drop. It is important to remember that the leading edge of any fast transient passed by a diode may be modified by this phenomenon.

NOTE: The above waveform photos are multiple exposures.

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In Europe please write Tektronix Inc., Victoria, Ave., St. Sampsons, Guernsey C.I., for the address of the Tektronix Representative in your country.

***CAREER OPPORTUNITIES** now exist at Tektronix in the following fields: Instrument design, Circuit design and engineering, Cathode ray tubes, Electron physics, Solid state and semi-conductor devices. For information write to Irving Smith, Personnel Director.*

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NEWS New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 192A)

will expand and manage the company's sales, manufacturing and administrative departments in keeping with a planned program for growth.

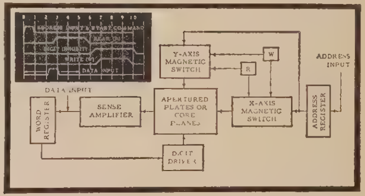
He has received both a Bachelor of Mechanical Engineering and a Bachelor of Science in Business Administration from Kansas State University. In addition, he has had further education in these fields at Bridgeport Engineering Institute and Cornell University.

After graduating from Midshipmen's school as honorary company sub-commander Lambert served as assistant gunnery officer on a destroyer in the Pacific. Upon completion of his military duties, he was employed as an engineer by the Yale & Towne Manufacturing Company and subsequently during a period of 8 years with the Burndy Corporation served in various management positions related to both manufacturing and sales. Lambert was directly responsible for the design and production of electrical devices for various Aircraft and Missile applications.

Coincident-Current Magnetic Memories

Rese Engineering, Inc., 731 Arch St., Philadelphia 6, Pa., announces Series 3100 Magnetic Memories, high speed coincident-current, random access storage units with a range of storage capacities from 128 to 4096 words and from 4 to 64 bits per word, permitting exact match of memory to arithmetic operations and instruction storage, editing, telemetering, multiplexing and data distribution, communication links and displays, and a multitude of data processing and control equipment.

Operating with adddress to address cycles as low as 10 microseconds, these transistor operated memories accept digital information either synchronously or asynchronously, store the information in randomly specified or sequential addresses, and can be supplied with binary or binary coded decimal address.



Series 3100 Magnetic Memories require only data and address signals and a read or write cycle start pulse from external data processing equipment. Input signals may be pulses or levels at 0 or −6 volts. When sequential address is made to each storage location, the address register is operated as a counter, relieving the external equipment of certain circuit requirements. Stored information is held indefinitely, or until recalled by the external data processing equipment, when it may be called up in random or sequential order. Input-output data may be transferred in parallel or in series by an in-out shift register, which also serves as the regeneration register. Output data is taken as a level from flip-flop register at 0 or −6 volts.

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And Why It Was Chosen By

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The Problem:

The Long Island Rail Road needed a rugged, portable, all-purpose field analyzer for checking signal relays and line circuits . . . and for measuring and adjusting both AC and DC track circuit voltages.

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After evaluating all available test instruments, the ***PRECISION*** Model 120 was chosen for its reliability and accuracy . . . and for the fact that it was so versatile that it could do a job that formerly required the use of several different test instruments.

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VOLT-OHM-MILLIAMMETER WITH MIRRORED-SCALE
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61 RANGES start lower and go higher than other instruments of its size and type
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DC POLARITY REVERSING SWITCH
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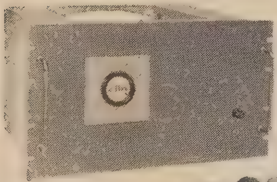

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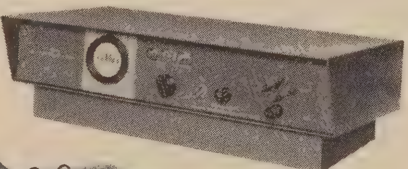

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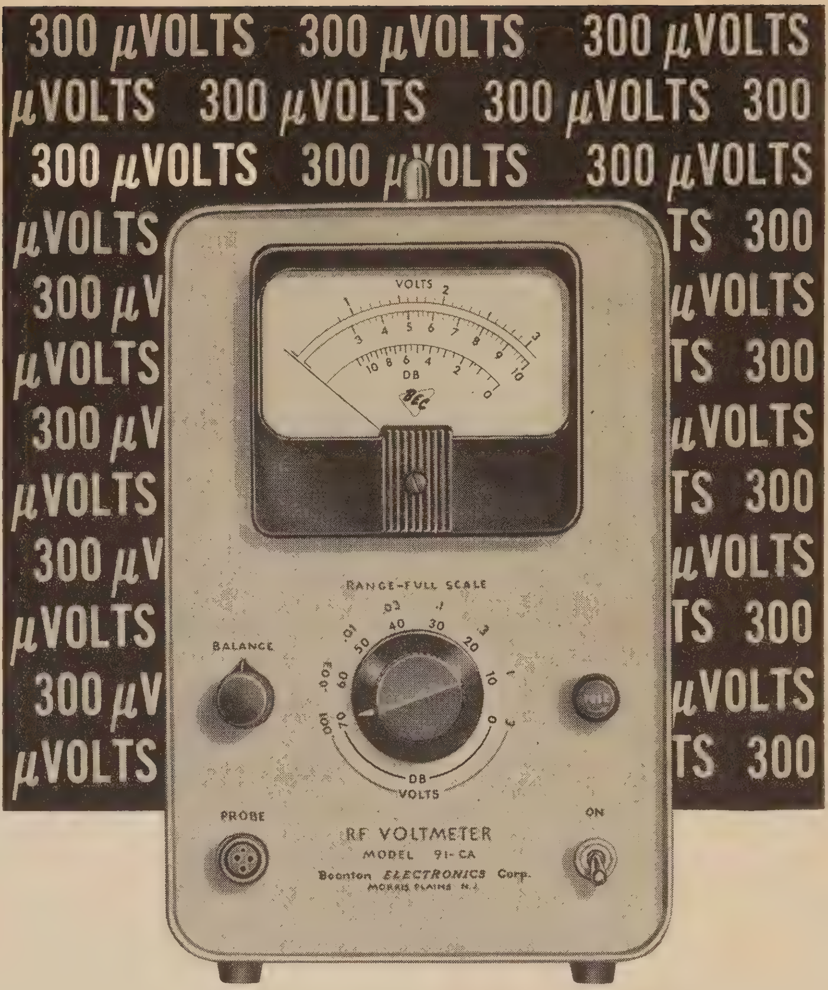


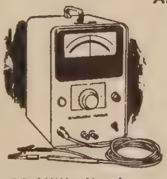
THE LEADER

in R.F. Voltage Measurements at Low Level

from 10 KC to 600 MC

MODEL 91-CA	MODEL 91-C
300 microvolts to 3 volts	**1000 microvolts to 3 volts**
Price: $495	Price: $395

ALSO MANUFACTURERS OF THE FOLLOWING INSTRUMENTS: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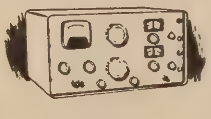
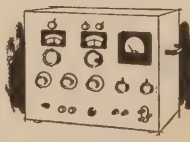

Inductance Bridge

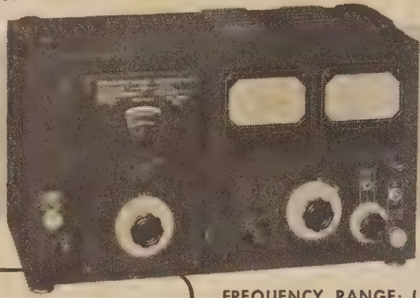

Capacitance Bridge

UHF Grid Dip Meter

Boonton ELECTRONICS Corp.
Morris Plains, N. J. • JEfferson 9-4210

EXTENDED *FREQUENCY RANGE*

with these STANDARD SIGNAL GENERATORS



MODEL 80
2 Mc to 400 Mc

MODEL 80-R
5 Mc to 475 Mc

FEATURES

- Direct-Reading scales and dials; individually calibrated.
- Convenient microvolt and DBM output scales.
- Accurate indication of output voltages at all levels.
- Low residual FM due to hum and noise.
- Provision for external pulse modulation.

SPECIFICATIONS

FREQUENCY RANGE: (Model 80) 2 to 400 Mc in 6 bands.
(Model 80-R) 5 to 475 Mc in 6 bands.

FREQUENCY ACCURACY: ± 0.5%

FREQUENCY DRIFT: Less than .1% after warm-up.

OUTPUT VOLTAGE: Continuously variable from 0.1 to 100,000 microvolts (−7 to −127 DBM).

OUTPUT ACCURACY: ±10% at 0.1 volt from 5 to 200 Mc.
±15% at 0.1 volt from 200 to 475 Mc.

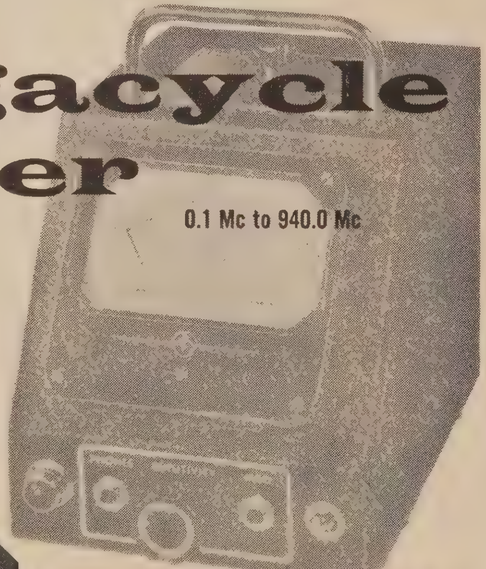
MODULATION: AM is continuously variable from 0 to 30%.
Internal modulation, 400 and 1000 cycles.
External modulation, 50 to 10,000 cycles.

RESIDUAL FM: Less than 500 cps at 450 Mc for Model 80-R, and correspondingly lower for both models at lower frequencies.

POWER SUPPLY: 117v, 50-60 cycles, 70 watts.

STILL THE BEST VALUE IN A SIGNAL GENERATOR—PRICE OF THE MODEL 80 IS $590, UNCHANGED SINCE 1945.

Megacycle Meter



0.1 Mc to 940.0 Mc

Determines resonant frequency of tuned circuits, antennas, transmission lines, by-pass condensers, chokes, etc. Measures inductance and capacitance. Also used as a signal generator, wave meter, frequency meter, and in many other applications.

This compact, lightweight grid-dip meter is available in the frequency ranges indicated.

Standard Model 59 complete	$168.00
UHF Model complete	$198.00
LF Model complete	$168.00
Combination all ranges	$380.00

F.O.B. Boonton, N.J.

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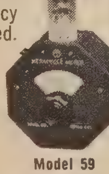

Model 59
Oscillator
2.2 Mc - 420 Mc

Model 59-LF
Oscillator
100 Kc - 4.5 Mc

Model 59-UHF
Oscillator
420 Mc - 940 Mc

Laboratory Standards

MEASUREMENTS
A McGraw-Edison Division
BOONTON, NEW JERSEY

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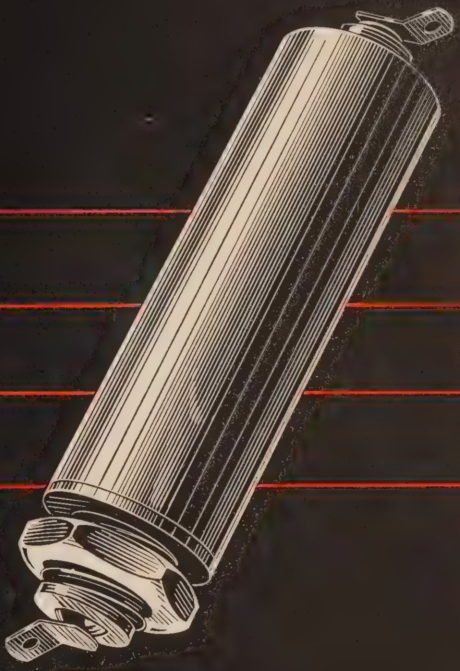
CDE *Consistently Dependable Capacitors*



miniaturized pi filters suppress electronic interference from 150 kc to 10,000 mc

C-D *miniaturized* tubular pi filters and 3-terminal feed-thru capacitors suppress electronic interference effectively at any frequency from 150 kc to 10,000 mc. Regardless of your design requirements, the C-D Filter Laboratories can supply you with the exact suppression component you need with tubular shapes, neck-mounting designs and smallest possible case sizes to save space and weight, enable easy installation. C-D miniaturized pi filters and feed-thru capacitors also provide better insertion loss per unit volume, weight and cost as compared to other types of suppression devices at identical ratings.

To obtain complete engineering data and specifications, write for Engineering Bulletins 171, 172 and 166 to Cornell-Dubilier Electric Corporation, South Plainfield, New Jersey. *Manufacturers of consistently dependable capacitors, filters and networks for electronics, thermonucleonics, broadcasting and utility use for 50 years.*

SPECIFICATIONS

Tubular Pi Filter TYPE NFR113

Voltage: 120 VAC (60 cycles), 300 VDC
Current: 0.5 Amperes
Dimensions: 1″ x $2\frac{11}{16}$″ Weight: 4.0 oz.

Feed-Through Capacitor TYPE NFT5W4P22W

Voltage: 125 VAC (60 cycles), 400 VDC
Current: 25.0 Amperes
Capacitance: 0.22 mfd.
Dimensions: $\frac{9}{16}$″ x $1\frac{29}{32}$″ Weight: 0.83 oz.

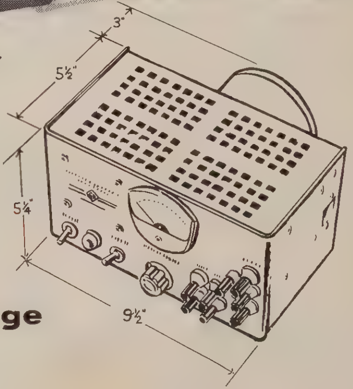
CDE **CORNELL-DUBILIER ELECTRIC CORPORATION**

AFFILIATED WITH FEDERAL PACIFIC ELECTRIC COMPANY

VOLTS
100
200
300
100
MA
200
ADJUSTABLE REGULATED
POWER SUPPLY
TYPE 1205-B
GENERAL RADIO COMPANY
0–300V
6.3V
6.3V
OUTPUT VOLTAGE
METER
VOLTS
MA
POWER
B+
OFF
OFF
–150V

Small
and Powerful

REGULATED POWER SUPPLY



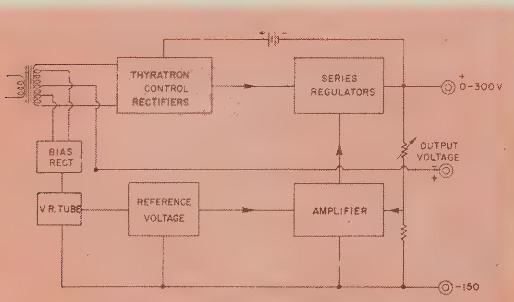
Continuously Adjustable 0 to 300v, dc, at 200 ma *

Plus . . . -150v, dc, at 5 ma

. . . two 6.3v, ac, unregulated outputs at 5a each
(may be connected in series or parallel)

. . . all from a compact package

120 Watts in 0.2 Cubic-Foot Package . . . Excellent performance is obtained by using two regulator circuits. A high-efficiency controlled rectifier maintains the optimum operating voltage for a series regulator, regardless of line-voltage changes, load changes, or changes in output voltage setting. Wide-band regulator circuits and high-frequency by-passing of the output make for low output impedance over a wide frequency range. A large capacity fan provides cooling without dependence on convection, permitting the stacking of any number of units.


THYRATRON CONTROL RECTIFIERS
SERIES REGULATORS
+ 0-300 V
OUTPUT VOLTAGE
BIAS RECT
V.R. TUBE
REFERENCE VOLTAGE
AMPLIFIER
-150

Regulator Block Diagram

*

Ripple: less than 1 mv (120c)

Regulation: 0.75v for ±10% line change: 0.1v from no load to full load

Output Impedance: Approximately 0.3Ω plus 10 μh

Type 1205-B Adjustable Regulated Power Supply........$290

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june 1960
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PART II
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ABSTRACTS
AND
REFERENCES
1959

VOLUME 48, NUMBER 6, PART II

June, 1960

published monthly by The Institute of Radio Engineers, Inc.

Proceedings of the IRE®

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(A) Abstract, (B) Book Review, (C) Note of Correction, (D) Discussion

Abbreviations used in the Index

a.c. = alternating current
d.c. = direct current
h.v. = high voltage
l.v. = low voltage
a.f. = audio frequency
i.f. = intermediate frequency
r.f. = radio frequency, including:—
v.l.f. = very low frequency, <30 kc/s
l.f. = low frequency, 30–300 kc/s
m.f. = medium frequency, 300–3000 kc/s
h.f. = high frequency, 3–30 Mc/s
v.h.f. = very high frequency, 30–300 Mc/s
u.h.f. = ultra high frequency, >300 Mc/s
a.m. = amplitude modulation
f.m. = frequency modulation
p.m. = pulse modulation, including:—
p.a.m. = pulse amplitude modulation
p.c.m. = pulse code modulation
p.f.m. = pulse frequency modulation
p.ph.m. = pulse phase modulation
p.p.m. = pulse position modulation
p.w.m. = pulse width modulation
ph.m. = phase modulation
v.m. = velocity modulation

c.w. = continuous wave
$\left.\begin{array}{l}\text{i.c.w.}\\ \text{m.c.w}\end{array}\right\} =$ modulated c.w.
s.w.* = short wave
u.s.w.* = ultra short wave
λ = wavelength
c.r. = cathode ray
c.r.o. = cathode ray oscilloscope
d.f. = direction finding
e.m. = electromagnetic, *but*
e.m.f. = electromotive force
a.f.c. = automatic frequency control
a.g.c. = automatic gain control
a.ph.c. = automatic phase control
a.v.c. = automatic volume control
m.u.f. = maximum usable frequency
p.p.i. = plan position indicator
s.s.b. = single sideband
d.s.b. = double sideband
s.w.r. = standing wave ratio
v.f.o. = variable frequency oscillator
R/T = radiotelephony
W/T = wireless telegraphy
TV = television

* No clearly defined limits

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A name followed by "and" is that of the first author of a jointly written paper, while the word "with" indicates that the name indexed is that of the second author.

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1052	For 'F. A. Vaniar' read 'F. A. Veniar'
1529	In line 5, for 'auroral' read 'annual'
1824	In line 7, for 'frequency band' read 'energy band'
1958	For 'J. F. Ditton, Jr' read 'J. F. Dillon, Jr'
1986	Change U.D.C. number to 621.384.8 : 537.54
2113	In line 4, for 'three-part' read 'three-port'
2159	In line 7, for 'joints' read 'points'
2278	In title, for 'Electric' read 'Elastic'
2408	In line 7, for '605-line' read '625-line'
2669	For 'S. Asanabo' read 'S. Asanabe'
2720	Change U.D.C. number to 621.384.8 : 537.54
2831	In title, for 'TE$^{\circ}_{10}$–TE$^{\circ}_{01}$' read 'TE$^{\square}_{10}$–TE$^{\circ}_{01}$'
2857	In title, for '$m\sqrt{N}$' read '$N^{1/m}$'
2958	In line 4, for 'change-exchange' read 'charge-exchange'
3030	In line 5, for 'function' read 'junction'
3136	In line 5, for '3136' read '3138
3171	For 'W. R. Aitken' read 'W. R. Aiken'
3256	Change U.D.C. number to 538.566 : 535.42
3350	Change U.D.C. number to 537.311.3 : 539.23
3836	For 'J. L. Veshaeghe' read 'J. L. Verhaeghe'

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1405 of 1957	July 1957, Vol. AP-5, No. 3, p. 313
2959 of 1957	Dec. 1958, Vol. 5, No. 6, pp. 510–513
84 of 1958	Jan. 1959, Vol. 6, No. 1, p. 80
295 of 1958	Sept. 1959, Vol. 36, No. 9, p. 352
971 of 1958	Sept. 1958, Vol. 29, No. 9, p. 1383
1228 of 1958	Dec. 1959, Vol. 47, No. 12, p. 2105
1858 of 1958	April 1958, Vol. 3, No. 30, p. 312
1892 of 1958	April 1958, Vol. 3, No. 30, p. 312
3028 of 1958	Sept. 1958, Vol. 29, No. 9, p. 1383
3271 of 1958	Dec. 1959, Vol. 47, No. 12, p. 2084
3472 of 1958	Dec. 1958, Vol. 18, No. 12, p. 714
3544 of 1958	15th Dec. 1958, Vol. 112, No. 6, p. 2139
3890 of 1958	15th Sept. 1959, Vol. 115, No. 6, p. 1778
3902 of 1958	15th March 1959, Vol. 113, No. 6, p. 1697
3962 of 1958	Dec. 1958, Vol. 46, No. 12, p. 1913
173 of 1959	15th March 1959, Vol. 113, No. 6, p. 1696
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501 of 1959	1st June 1959, Vol. 73, No. 474, p. 976
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Acta Polytechnica Scandinavica, Publishing Office, Box 5073, Stockholm 5, Sweden. (*Acta polyt. scand.*)

Acustica, S. Hirzel Verlag, Stuttgart-N, Germany. (*Acustica*)

Advances in Physics, Taylor & Francis Ltd, Red Lion Court, Fleet Street, London, E.C.4, England. (*Advances Phys.*)

Akusticheskii Zhurnal, Moskva, B-64, Podsosenskii per., 21, U.S.S.R. (*Akust. Zh.*)

Akustische Beihefte, as for Acustica. (*Akust. Beihefte*)

Alta Frequenza, Associazione Elettrotecnica Italiana, Milano (202), Via S. Paolo 10, Italy. (*Alta Frequenza*)

Annalen der Physik, J. A. Barth, Leipzig C1, Salomonstrasse 18B, East Germany. (*Ann. Phys., Lpz.*)

Annales de Géophysique, Service des Publications du C.N.R.S., 13 Quai Anatole France, Paris 7ᵉ, France. (*Ann. Géophys.*)

Annales de Physique, Masson & Cie, 120 Boulevard Saint-Germain, Paris 6ᵉ, France. (*Ann. Phys., Paris*)

Annales de Radioélectricité, 10 rue Carducci, Paris 19ᵉ. France. (*Ann. Radioélect.*)

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A.T.E. Journal, Automatic Telephone & Electric Co. Ltd, Strowger Works, Liverpool 7, England. (*A.T.E. J.*)

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Avtomatika i Telemekhanika, Moskva, I-53, Kalanchevskaya ul., 15a, U.S.S.R. (*Avtomatika i Telemekhanika*)

A.W.A. Technical Review, Amalgamated Wireless (Australasia) Ltd, Sydney, Australia. (*A.W.A. tech. Rev.*)

B

B.B.C. Engineering Division Monographs, British Broadcasting Corporation, 35 Marylebone High Street, London, W.1, England. (*B.B.C. Engng Div. Monographs*)

Beama Journal, British Electrical and Allied Manufacturers' Association, 36 Kingsway, London, W.C.2, England. (*Beama J.*)

Bell Laboratories Record, 463 West Street, New York 14, N.Y., U.S.A. (*Bell Lab. Rec.*)

Bell System Technical Journal, American Telephone and Telegraph Company, 195 Broadway, New York 7, N.Y., U.S.A. (*Bell Syst. tech. J.*)

British Communications & Electronics, Heywood & Co. Ltd, Drury House, Russell Street, Drury Lane, London, W.C.2, England. (*Brit. Commun. Electronics*)

British Journal of Applied Physics, 47 Belgrave Square, London, S.W.1, England. (*Brit. J. appl. Phys.*)

Brown Boveri Review, Baden, Switzerland. (*Brown Boveri Rev.*)

Bulletin de l'Association Suisse des Électriciens, Seefeldstrasse 301, Zürich 8, Switzerland. (*Bull. schweiz. elektrotech. Ver.*)

Bulletin of the Technical University Istanbul, Istanbul Teknik Üniversitesi, Gümüssuyu, Istanbul, Turkey. (*Bull. tech. Univ. Istanbul*)

C

Câbles & Transmission, Sotelec, 16 rue de la Baume, Paris 8e, France. (*Câbles & Transm.*)

Cahiers de Physique, 165 rue de Sèvres, Paris 15e, France. (*Cah. Phys.*)

Canadian Electronics Engineering, Maclean-Hunter Publishing Co. Ltd, P.O. Box 100, Toronto, Canada. (*Canad. Electronics Engng*)

Canadian Journal of Physics, National Research Council, Ottawa 2, Ont., Canada. (*Canad. J. Phys.*)

Chalmers tekniska Högskolas Handlingar Gumperts Förlag, Göteborg, Sweden (*Chalmer. tek. Högsk. Handl.*)

Communication and Electronics, American Institute of Electrical Engineers, 20th and Northampton Streets, Easton, Pa, U.S.A. (*Commun. & Electronics*)

Communications on Pure and Applied Mathematics, Interscience Publishers Inc., 250 Fifth Avenue, New York 1, N.Y., U.S.A. (*Commun. pure appl. Math.*)

Comptes Rendus Hebdomadaires des Séances de l'Académie des Sciences, Gauthier-Villars, 55 Quai des Grands-Augustins, Paris 6e, France. (*C. R. Acad. Sci., Paris*)

D

Doklady Akademii Nauk S.S.S.R., Moskva, B-64, Podsosenskii per., 21, U.S.S.R. (*Dokl. Ak. Nauk S.S.S.R.*)

E

E.B.U. Review, 32 Avenue Albert Lancaster, Bruxelles 18, Belgium. (*E.B.U. Rev.*)

Electrical Communication, International Telephone and Telegraph Corporation, 67 Broad Street, New York 4, N.Y., U.S.A. (*Elect. Commun.*)

Electrical Engineering, American Institute of Electrical Engineers, 33 West 39th Street, New York 18, N.Y., U.S.A. (*Elect. Engng, N.Y.*)

Electrical Journal, Bouverie House, 154 Fleet Street, London, E.C.4, England. (*Elect. J.*)

Electrical Manufacturing, 205 East 42nd Street, New York 17, N.Y., U.S.A. (*Elect. Mfg*)

Electrical Review, Dorset House, Stamford Street, London, S.E.1, England. (*Elect. Rev., Lond.*)

Electronic Applications, N. V. Philips' Gloeilampenfabrieken, Technical and Scientific Literature Department, Eindhoven, Netherlands. (*Electronic Applic.*)

Electronic Engineering, 28 Essex Street, London, W.C.2, England. (*Electronic Engng*)

Electronic Equipment Engineering, Sutton Publishing Company Inc., 172 South Broadway, White Plains, N.Y., U.S.A. (*Electronic Equipm. Engng*)

Electronic Industries, Chestnut and 56th Sts, Philadelphia 39, Pa, U.S.A. (*Electronic Ind.*)

Electronic & Radio Engineer, Iliffe & Sons Ltd, Dorset House, Stamford Street, London, S.E.1, England. (*Electronic Radio Engr*)

Electronics, 330 West 42nd Street, New York 36, N.Y., U.S.A. (*Electronics*)

Elektronische Rundschau, Verlag für Radio-Foto-Kinotechnik G.m.b.H., Berlin-Borsigwalde, Eichborndamm 141–167, Germany. (*Elektronische Rundschau*)

Elektrosvyaz', Moskva, K-9, ul. Gor'kogo, 7, 8-i pod"ezd, 3-i etazh, U.S.S.R. (*Elektrosvyaz'*)

Elektrotechnik und Maschinenbau, Journal of the Elektrotechnischer Verein Österreichs, Springer Verlag, Wien I, Mölkerbastei 5, Austria. (*Elektrotech. u. Maschinenb.*)

Elektrotechnische Zeitschrift, Edition A & B, VDE-Verlag G.m.b.H., Berlin-Charlottenburg 2, Bismarckstrasse 33, Germany. (*Elektrotech. Z.*)

Endeavour, Imperial Chemical Industries Ltd, North Block, Thames House, Millbank, London, S.W.1, England. (*Endeavour*)

Engineer, 28 Essex Street, London, W.C.2, England. (*Engineer, Lond.*)

Engineering, 36 Bedford Street, London, W.C.2, England. (*Engineering, Lond.*)

Ericsson Review, Telefonaktiebolaget L. M. Ericsson, Stockholm 32, Sweden. (*Ericsson Rev.*)

Ericsson Technics, as for Ericsson Review. (*Ericsson Tech.*)

F

Fizika Tverdogo Tela, Leningrad, V-164, Mendeleevskaya lin., 1, U.S.S.R. (*Fiz. Tverdogo Tela*)

Frequenz, Fachverlag Schiele & Schön G.m.b.H., Berlin S.W.61, Markgrafenstrasse 11, Germany. (*Frequenz*)

Funk-Technik, Verlag für Radio-Foto-Kinotechnik G.m.b.H., Berlin-Borsigwalde, Eichborndamm 141–167, Germany. (*Funk-Technik, Berlin*)

G

G.E.C. Journal, General Electric Company Ltd, Magnet House, Kingsway, London, W.C.2, England. (*G.E.C. J.*)

G.E.C. Telecommunications, General Electric Company Ltd, Coventry, England. (*G.E.C. Telecommun.*)

Geofisica Pura e Applicata, Istituto Geofisico Italiano, Milano, Piazza Leonardo da Vinci 12, Italy. (*Geofis. pura appl.*)

Geophysical Journal of the Royal Astronomical Society, Burlington House, London, W.1, England. (*Geophys. J. R. astr. Soc.*)

H

Helvetica Physica Acta, Journal of the Schweizerische Physikalische Gesellschaft, Birkhäuser Verlag, Basel, Switzerland. (*Helv. phys. Acta*)

Hochfrequenztechnik und Elektroakustik, Akademische Verlagsgesellschaft Geest & Portig K.-G., Leipzig C1, Sternwartenstr. 8, East Germany. (*Hochfrequenztech. u. Elektroakust.*)

I

IBM Journal of Research and Development, International Business Machines Corporation, 590 Madison Avenue, New York 22, N.Y., U.S.A. (*IBM J. Res. Developm.*)

Indian Journal of Physics (and Proceedings of the Indian Association for the Cultivation of Science), Jadavpur, Calcutta 32, India. (*Indian J. Phys.*)

Izvestiya Akademii Nauk S.S.S.R. (*a*) seriya fizicheskaya, Moskva, B-64, Podsosenskii per., 21, U.S.S.R., (*b*) seriya geofizicheskaya, Moskva, B. Gruzinskaya, 10, U.S.S.R., (*c*) otdelenie tekhnicheskikh nauk, Moskva, M. Khariton'evskii per., 4, U.S.S.R. (*Izv. Ak. Nauk S.S.S.R.*, (*a*) *ser. fiz.*, (*b*) *ser. geofiz.*, (*c*) *otd. tekh. nauk*)

J

Journal of the Acoustical Society of America, American Institute of Physics, 335 East 45th Street, New York 17, N.Y., U.S.A. (*J. acoust. Soc. Amer.*)

Journal of the American Ceramic Society, 20th and Northampton Streets, Easton, Pa, U.S.A. (*J. Amer. ceram. Soc.*)

Journal of Applied Physics, American Institute of Physics, 335 East 45th Street, New York 17, N.Y., U.S.A. (*J. appl. Phys.*)

Journal of Atmospheric and Terrestrial Physics, Pergamon Press Ltd, 4 & 5 Fitzroy Square, London, W.1, England. (*J. atmos. terr. Phys.*)

Journal of the Audio Engineering Society, P.O. Box 12, Old Chelsea Station, New York 11, N.Y., U.S.A. (*J. audio Engng Soc.*)

Journal of the British Institution of Radio Engineers, 9 Bedford Square, London, W.C.1, England. (*J. Brit. Instn Radio Engrs*)

Journal of the British Interplanetary Society, 12 Bessborough Gardens, London, S.W.1, England. (*J. Brit. interplan. Soc.*)

Journal of the Electrochemical Society, 1860 Broadway, New York 23, N.Y., U.S.A. (*J. electrochem. Soc.*)

Journal of Electronics and Control, Taylor & Francis Ltd, Red Lion Court, Fleet Street, London, E.C.4, England. (*J. Electronics Control*)

Journal of the Franklin Institute, Benjamin Franklin Parkway at Twentieth Street, Philadelphia 3, Pa, U.S.A. (*J. Franklin Inst.*)

Journal of Geomagnetism and Geoelectricity, Society of Terrestrial Magnetism and Electricity of Japan, Geophysical Institute, Kyoto University, Kyoto, Japan. (*J. Geomag. Geoelect.*)

Journal of Geophysical Research, 1515 Massachusetts Avenue, N.W., Washington 5, D.C., U.S.A. (*J. geophys. Res.*)

Journal of the Indian Institute of Science, Indian Institute of Science, Bangalore 12, India. (*J. Indian Inst. Sci.*)

Journal of the Institute of Navigation, John Murray Ltd, 50 Albemarle Street, London, W.1, England. (*J. Inst. Nav.*)

Journal of the Institution of Telecommunication Engineers, Post Box 481, New Delhi, India. (*J. Instn Telecommun. Engrs, India*)

Journal of Mathematics and Physics, Massachusetts Institute of Technology, Cambridge 39, Mass., U.S.A. (*J. Math. Phys.*)

Journal of Meteorology, Prince and Lemon Streets, Lancaster, Pennsylvania, U.S.A (*J. Met.*)

Journal of the Optical Society of America, American Institute of Physics, 335 East 45th Street, New York 17, N.Y., U.S.A. (*J. opt. Soc. Amer.*)

Journal of the Physical Society of Japan, Maruzen Publishing Co., P.O. Box 605 Central, Tokyo, Japan. (*J. phys. Soc. Japan*)

The Journal of the Physics and Chemistry of Solids, Pergamon Press Ltd, 4 & 5 Fitzroy Square, London, W.1, England. (*J. Phys. Chem. Solids*)

Journal de Physique et le Radium, 12 place Henri-Bergson, Paris 8e, France. (*J. Phys. Radium*)

Journal of the Radio Research Laboratories, Ministry of Posts and Telecommunications, Koganei-shi, Tokyo, Japan. (*J. Radio Res. Labs, Japan*)

Journal of Research of the National Bureau of Standards, U.S. Government Printing Office, Washington 25, D.C., U.S.A. (*J. Res. nat. Bur. Stand.*)

Journal of Scientific Instruments, 47 Belgrave Square, London, S.W.1, England. (*J. sci. Instrum.*)

Journal of the Society of Motion Picture and Television Engineers, 55 West 42nd Street, New York 36, N.Y., U.S.A. (*J. Soc. Mot. Pict. Telev. Engrs*)

Journal of the Television Society, 166 Shaftesbury Avenue, London, W.C.2, England. (*J. Telev. Soc.*)

M

Marconi Review, Marconi House, Chelmsford, England. (*Marconi Rev.*)

Metal Industry, Iliffe & Sons Ltd, Dorset House, Stamford Street, London, S.E.1, England. (*Metal Ind., Lond.*)

Metallurgia, 31 King Street West, Manchester 3, England. (*Metallurgia, Manchr*)

Meteorological Magazine, Her Majesty's Stationery Office, York House, Kingsway, London, W.C.2, England. (*Met. Mag., Lond.*)

Microtecnic, 23 Avenue de la Gare, Lausanne, Switzerland. (*Microtecnic*)

Modern Plastics, 575 Madison Avenue, New York 22, N.Y., U.S.A. (*Mod. Plast.*)

Monthly Notices of the Royal Astronomical Society, Burlington House, London, W.1, England. (*Mon. Not. R. astr. Soc.*)

Mullard Technical Communications, Mullard House, Torrington Place, London, W.C.1, England. (*Mullard tech. Commun.*)

N

Nachrichtentechnik, V.E.B. Verlag Technik, Berlin C2, Oranienburger Str. 13/14, East Germany. (*NachrTech.*)

Nachrichtentechnische Zeitschrift, F. Vieweg & Sohn, (20b) Braunschweig, Burgplatz 1, Germany. (*Nachrichtentech. Z.*)

Nature, Macmillan & Co. Ltd, St. Martin's Street, London, W.C.2, England. (*Nature, Lond.*)

Naturwissenschaften, Springer Verlag, Berlin-Wilmersdorf, Heidelberger Platz 3, Germany. (*Naturwissenschaften*)

Note Recensioni e Notizie, Istituto Superiore delle Poste e delle Telecomunicazioni, Viale Trastevere 189, Roma, Italy. (*Note Recensioni Notiz.*)

Nucleonics, 330 West 42nd Street, New York 36, N.Y., U.S.A. (*Nucleonics*)

Nuovo Cimento, Editore Nicola Zanichelli, Bologna, Via Irnerio 34, Italy. (*Nuovo Cim.*)

O

Observatory, Royal Greenwich Observatory, Herstmonceux Castle, Hailsham, Sussex, England. (*Observatory*)

l'Onde Électrique, Éditions Chiron, 40, rue de Seine, Paris 6e, France. (*Onde élect.*)

Optik, Wissenschaftliche Verlagsgesellschaft m.b.H., Stuttgart 1, Postfach 40, Germany. (*Optik, Stuttgart*)

P

Philips Research Reports, N.V. Philips' Gloeilampenfabrieken, Eindhoven, Netherlands. (*Philips Res. Rep.*)

Philips Technical Review, as for Philips Research Reports. (*Philips tech. Rev.*)

Philips Telecommunication Review, Philips Telecommunication Division, P.O. Box 32, Hilversum, Netherlands. (*Philips Telecommun. Rev.*)

Philosophical Magazine, Taylor & Francis Ltd, Red Lion Court, Fleet Street, London, E.C.4, England. (*Phil. Mag.*)

Philosophical Transactions of the Royal Society, Burlington House, Piccadilly, London, W.1, England. (*Phil. Trans.*)

Physica, Physica Foundation, Lucas Bolwerk 4, Utrecht, Netherlands. (*Physica*)

Physical Review, American Institute of Physics, 335 East 45th Street, New York 17, N.Y., U.S.A. (*Phys. Rev.*)

Physical Review Letters, American Institute of Physics, 335, East 45th Street, New York 17, N.Y., U.S.A. (*Phys. Rev. Lett.*)

Physics and Chemistry of Solids. See Journal of the Physics and Chemistry of Solids.

Point to Point Telecommunications, Communications Division, Marconi's Wireless Telegraph Co. Ltd, Chelmsford, England. (*Point to Point Telecommun.*)

Post Office Electrical Engineers' Journal, Engineer-in-Chief's Office, Alder House, Aldersgate Street, London, E.C.1, England. (*P.O. elect. Engrs' J.*)

Poste e Telecomunicazioni, Roma, Via della Vite 107, Italy. (*Poste e Telecomunicazioni*)

Priroda, Moskva, Tsentr, Malyi Khariton'evskii per., 4, U.S.S.R. (*Priroda, Mosk.*)

Proceedings of the Cambridge Philosophical Society (Mathematical and Physical Sciences), Cambridge University Press, Bentley House, 200 Euston Road, London, N.W.1, England. (*Proc. Camb. phil. Soc.*)

Proceedings of the Institute of Radio Engineers, 1 East 79th Street, New York 21, N.Y., U.S.A. (*Proc. Inst. Radio Engrs*)

Proceedings of the Institution of Electrical Engineers, Parts A, B and C, Savoy Place, London, W.C.2, England. (*Proc. Instn elect. Engrs*)

Proceedings of the Institution of Radio Engineers, Australia, Science House, 157 Gloucester Street, Sydney, N.S.W., Australia. (*Proc. Instn Radio Engrs Aust.*)

Proceedings of the Physical Society, 1 Lowther Gardens, Prince Consort Road, London, S.W.7, England. (*Proc. phys. Soc.*)

Proceedings of the Royal Society, Burlington House, Piccadilly, London, W.1, England. (*Proc. roy. Soc.*)

Progress of Theoretical Physics, The Publication Office, Yukawa Hall, Kyoto University, Kyoto, Japan. (*Progr. theor. Phys.*)

Q

QST, American Radio Relay League Inc., 38 La Salle Road, West Hartford 7, Conn., U.S.A. (*QST*)

Quarterly of Applied Mathematics, Brown University, Providence 12, R.I., U.S.A. (*Quart. appl. Math.*)

Quarterly Journal of Mathematics, Oxford University Press, Amen House, London, E.C.4, England. (*Quart. J. Math.*)

Quarterly Journal of Mechanics and Applied Mathematics, Oxford University Press, Amen House, London, E.C.4, England. (*Quart. J. Mech. appl. Math.*)

Quarterly Journal of the Royal Meteorological Society, 49 Cromwell Road, London, S.W.7, England. (*Quart. J. R. met. Soc.*)

R

Radio, Moskva, B-66, Novo-Ryazanskaya ul., 26, U.S.S.R. (*Radio, Mosk.*)

Radio & TV News, Ziff-Davis Publishing Company, 434 South Wabash Avenue, Chicago 5, Ill., U.S.A. (*Radio TV News*)

Radio-Electronics, 154 West 14th St., New York 11, N.Y., U.S.A. (*Radio-Electronics*)

Radioschau, Technischer Verlag Erb, Wien VI, Mariahilferstrasse 71, Austria. (*Radioschau*)

Radiotekhnika, Moskva, K-9, ul. Gor'kogo, 7, 3-i pod"ezd, U.S.S.R. (*Radiotekhnika, Mosk.*)

Radiotekhnika i Elektronika, Moskva, K-9, Mokhovaya, 11, U.S.S.R. (*Radiotekhnika i Elektronika*)

RCA Review, RCA Laboratories, Princeton, N.J., U.S.A. (*RCA Rev.*)

Referativnyi Zhurnal, Fizika, Moskva, D-129, Baltiiskaya ul., 14. U.S.S.R. (*Referativnyi Zh. Fiz.*)

Report of Ionosphere Research in Japan, Ionosphere Research Committee, Science Council of Japan, Ueno Park, Tokyo, Japan. (*Rep. Ionosphere Res. Japan*)

Reports of the Electrical Communication Laboratory, Nippon Telegraph and Telephone Public Corporation, 1551 Kichijoji, Musashino-shi, Tokyo, Japan. (*Rep. elect. Commun. Lab., Japan*)

Research, Butterworth's Scientific Publications Ltd, 88 Kingsway, London, W.C.2, England. (*Research, Lond.*)

Review of Scientific Instruments, American Institute of Physics, 335 East 45th Street, New York 17, N.Y., U.S.A. (*Rev. sci. Instrum.*)

Reviews of Modern Physics, American Institute of Physics, 335 East 45th Street, New York 17, N.Y., U.S.A. (*Rev. mod. Phys.*)

Revista Española de Electrónica, Apartado 5252, Barcelona, Spain. (*Rev. española Electrónica*)

Revista de Telecomunicación, Palacio de Comunicaciones, Madrid, Spain. (*Rev. Telecomunicación, Madrid*)

Revista Telegrafica Electrónica, Arbó Editores, Buenos Aires, Argentina. (*Res. telegr. Electrónica, Buenos Aires*)

Revue générale de l'Électricité, 12 place Henri-Bergson, Paris 8e, France. (*Rev. gén. Élect.*)

Revue HF, 55 rue Defacqz, Bruxelles, Belgium. (*Rev. HF, Brussels*)

Revue d'Optique, 3 & 5 Boulevard Pasteur, Paris 15e, France. (*Rev. d'Optique*)

Ricerca scientifica, Consiglio Nazionale delle Ricerche, Piazzale delle Scienze, 7, Roma, Italy. (*Ricerca sci.*)

R.S.G.B. Bulletin, New Ruskin House, Little Russell Street, London, W.C.1, England. (*R.S.G.B. Bull.*)

Rundfunktechnische Mitteilungen, H. H. Nölke G.m.b.H., Hamburg 20, Hegestrasse 40, Germany. (*Rundfunktech. Mitt.*)

S

Science, 1515 Massachusetts Avenue, N.W., Washington 5, D.C., U.S.A. (*Science*)

Science Reports of the Research Institutes Tohoku University, Series A and B, Tohoku University, Sendai, Japan. (*Sci. Rep. Res. Inst. Tohoku Univ.*)

Short Wave Magazine, 55 Victoria Street, London, S.W.1, England. (*Short Wave Mag.*)

Sylvania Technologist, Sylvania Electric Products Inc., Bayside, N.Y., U.S.A. (*Sylvania Technologist*)

T

Technical News Bulletin of the National Bureau of Standards, U.S. Government Printing Office, Washington 25, D.C., U.S.A. (*Tech. News Bull. nat. Bur. Stand.*)

Technische Mitteilungen aus dem Betriebslaboratorium für Rundfunk und Fernsehen, Agastrasse, Berlin-Adlershof, East Germany. (*Tech. Mitt. BRF, Berlin*)

Technische Mitteilungen PTT, Journal of the Swiss Post Office, Bern, Speichergasse 6, Switzerland. (*Tech. Mitt. PTT*)

Telefunken Zeitung, Telefunken G.m.b.H., Berlin-Charlottenburg 1, Ernst-Reuter-Platz, Haus der Elektrizität, Germany. (*Telefunken Ztg*)

Télévision, 42 rue Jacob, Paris 6e, France. (*Télévision*)

Tellus, Lindhagensgatan 124, Stockholm, Sweden. (*Tellus*)

Tijdschrift van het Nederlands Radiogenootschap, Jagtlustlaan 9, Santpoort-Zuid, Netherlands. (*Tijdschr. ned. Radiogenoot.*)

Toute la Radio, 9 rue Jacob, Paris 6e, France. (*Toute la Radio*)

Transactions of the Institute of Radio Engineers, 1 East 79th Street, New York 21, N.Y., U.S.A. (*Trans. Inst. Radio Engrs*)

Transactions of the South African Institute of Electrical Engineers, The Associated Scientific and Technical Societies of South Africa, P.O. Box 5907, Johannesburg, South Africa. (*Trans. S. Afr. Inst. elect. Engrs*)

TSF et TV, Éditions Chiron, 40 rue de Seine, Paris 6e, France. (*TSF et TV*)

U

Uspekhi Fizicheskikh Nauk, Moskva, V-71, Leninskii Prospekt, 15, U.S.S.R. (*Usp. fiz. Nauk*)

V

Le Vide, Journal of the Société française des Ingénieurs et Techniciens du Vide, 44 rue de Rennes, Paris 6e, France. (*Le Vide*)

W

Weather, 49 Cromwell Road, London, S.W.7, England. (*Weather*)

Wireless World, Iliffe & Sons Ltd, Dorset House, Stamford Street, London, S.E.1, England. (*Wireless World*)

Z

Zeitschrift für angewandte Mathematik und Physik, Birkhäuser-Verlag, Basel, Switzerland. (*Z. angew. Math. Phys.*)

Zeitschrift für angewandte Physik, Springer-Verlag, Berlin-Wilmersdorf, Heidelberger Platz 3, Germany. (*Z. angew. Phys.*)

Zeitschrift für Metallkunde, Dr. Riederer-Verlag G.m.b.H., Stuttgart, Marienstrasse 52, Germany. (*Z. Metallkde*)

Zeitschrift für Meteorologie, Akademie-Verlag G.m.b.H., Berlin W.1, Leipziger Strasse 3–4, East Germany. (*Z. Met.*)

Zeitschrift für Naturforschung, (14b) Tübingen, Postfach 61, Germany. (*Z. Naturf.*)

Zeitschrift für Physik, Springer-Verlag, Berlin, Wilmersdorf, Heidelberger Platz 3, Germany (*Z. Phys.*)

Zhurnal eksperimental'noi i teoreticheskoi Fiziki, Moskva, V-133, Vorob'evskoe shosse, 2, U.S.S.R. (*Zh. eksp. teor. Fiz.*)

Zhurnal tekhnicheskoi Fiziki, Leningrad V-164, Mendeleevskaya lin., 1, U S.S.R. (*Zh. tekh. Fiz.*)